Series II, Volume 1 April 26, 1956 Number 4

BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

PROGRAMME OF THE

1956 WASHINGTON MEETING

AT

WASHINGTON, D. C.

April 26, 27, and 28

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BULLETIN

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AMERICAN PHYSICAL SOCIETY

1956 WASHINGTON MEETING, APRIL 26, 27, AND 28, 1956

THE **1956 Spring Meeting of the American Physical Society** will be held in Washington, D. C., on Thursday, Friday, and Saturday, **April 26, 27, and 28, 1956.** Some of the scientific sessions will be held in the Sheraton Park Hotel, some in the Shoreham Hotel, and some in the National Bureau of Standards. The welcome availability of the Shoreham has enabled us to do without some of the less congenial halls used at last year's corresponding meeting; but it is nonetheless to be feared that some of our sessions will be unpleasantly congested. The early hours set for beginning some of the Friday sessions are imposed by the fact that we are not allowed to use certain halls later than 4 P.M. on that day. R. D. Huntoon has assumed for the second time the tremendous burdens of the Chairmanship of the Local Committee, insufficiently realized by nearly all of our members.

Last-minute correspondence to officers, session chairmen, and members generally should be addressed in care of the chairman of the Local Arrangements Committee, Room 112 C, Sheraton Park Hotel.

Hotel. All room reservations are to be made by writing to the Sheraton Park Hotel, Washington 8, D. C., with mention of the fact that the writer is a member of the American Physical Society coming to its meeting. Some of those who write will find themselves assigned to the Sheraton Park, some to the Shoreham, some to the Windsor Park or the Hotel 2400, or possibly others. Write immediately if you have not already done so. This notice has already appeared in two issues of the Bulletin.

The **main registration desk** will be located in the Sheraton Park Hotel, and an ancillary registration desk in the Shoreham. Registration may be effected (with payment of one dollar) and dinner tickets may be bought at either; the blackboards with announcements of messages, post-deadline papers, and other information will be stationed only at the Sheraton Park.

A **symposium on transmutation by heavy-ion bombardment** will be held on Thursday morning (Session A). A **symposium on trends in the application of computing machines to problems of physics** will be held on Saturday morning (Session S).

Our two most recent **Nobel Laureates,** P. Kusch and W. E. Lamb, will give addresses before the Society on Thursday afternoon (Session H).

Invited papers are sprinkled throughout the programme; the reader is asked to consult the Epitome for the authors and the main text for the authors and the titles.

Our **Division of Chemical Physics** will hold a Business Session during Session PA on Friday afternoon.

Three hundred and ninety-three contributed papers are distributed among thirty-three sessions. Last year the number was 394, and the previous year 406. One holds one's breath at this sign of stabilization of the Washington meeting. But even now the number is far too great to permit of the avoidance of simultaneous scheduling of papers of common interest, and also it limits the number of invited papers. The latter drawback might be reduced by seeking additional halls, but the former only at the price of extending the meeting to four days. The papers in theoretical physics are fewer than last year, but the shrinkage here is more than offset by the increase in the categories "radioactive nuclei" and "transmutation and nuclear energy levels." The old-fashioned meson is losing ground to the newfangled particles for which no good collective name has been proposed even yet.

The thanks of the Society are due Robert Serber, Jack Steinberger, and C. S. Wu for arranging the abstracts in theoretical physics, meson and strange-particle physics, and radioactive nuclei, respectively. The Secretary apologizes to S. Borowitz who performed a similar service for the 1956 New York meeting, and whose name was distorted into Borowski in the acknowledgment.

There will be **no placement register** at this meeting.

As at the past three meetings, the **Book Exhibit** will be located in the Sheraton Park Hotel.

The **banquet of the Society** will be held on Friday evening at seven in the Terrace Room of the Shoreham Hotel, scene of many of our dinners of the recent past, though not of last year's. At this banquet the Scott Medal and premium will be awarded by the City of Philadelphia to our distinguished colleague, J. W. Beams. Something of the history of this award is told in the Bulletin for our Baltimore meeting of March, 1955. The after-dinner speaker will be Arthur Roberts. The price of the dinner will be four dollars. Use the form on page 239 of this Bulletin for advance reservation. If you do not use it, watch vigilantly for announcements on the blackboards concerning the day and hour after which tickets may no longer be available.

Tea. The staff of the National Bureau of Standards will be host to the Society at tea, which they will offer to the members and guests of the Society at the Manse (on the Bureau grounds) from 4:30 to 6:30 P.M. on Thursday.

The **ladies' programme** has been arranged by Mrs. Francis M. Defandorf. On Friday, April 27th, the wives of the local members will provide transportation for a tour of either Mt. Vernon, Woodlaw, or Lee Mansion. Upon completion of the tour, each group will be driven directly to the Congressional Country Club for luncheon ($2.50). The selection of the tour desired must be announced at the time the luncheon tickets are purchased at the ladies' registration desk; the deadline is 5:00 P.M., Thursday, April 26.

The **Nominating Committee** of the American Physical Society will meet on Friday at 4:00 P.M. in the West Room of the Shoreham Hotel, unless contrary notice is received by its members from its chairman. The members of this Committee are R. T. Birge (*Chairman*), D. Alpert, J. G. Daunt, W. A. Fowler, S. A. Goudsmit, T. H. Osgood, N. F. Ramsey, Robert Serber, and W. H. Zinn.

The **Council** of the American Physical Society will meet on Wednesday, April 25, at 1:30 P.M. in the Conference Room of the South Building of the National Bureau of Standards, unless contrary notice is distributed to its members.

Post-deadline ten-minute papers, pertaining to very recent achievements of very special importance, will be considered for admission to a special supplementary programme if the abstracts are received at the office of the Society not later than Friday, April 20. The abstracts will not be published. The titles of such papers as may be accepted will be written on a blackboard near the registration desk, and there will be opportunity to give these papers at the end of Session H.

Prospective meetings and deadlines of the Society are listed on pages 158–160 of this Bulletin, together with instructions for the preparation of abstracts.

Errata pertaining to abstracts in this issue will be published in a subsequent issue of the Bulletin if received not later than Monday, April 30, by Miss Ruth Bryans, American Institute of Physics, 57 East 55th Street, New York 22, New York. Do not send in the abstracts marked with corrections. Write out the corrections in the form "Instead of . . . read. . . ." Add nothing.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

Preliminary Announcement of the 1956 New Haven Meeting

The 1956 Summer Meeting in the East will be held at New Haven, Connecticut, in the buildings of Yale University, on Thursday, Friday, and Saturday, June 21, 22, and 23, 1956. From the Chairman of the Local Committee we have the following information about places to reside.

(a) *Dormitory accommodations will be available,* in the Silliman and Timothy Dwight Colleges of Yale University, for single men, single women, and married couples, from Wednesday evening, June 20, to Saturday afternoon, June 23. The over-all charge will be $14.00 for the three-day period. Advance reservations are to be made by writing to Professor W. W. Watson, Department of Physics, Yale University, New Haven 11, Connecticut.

(b) *Recommended hotels* are the Taft (singles $5.50 to $7.50, doubles $9 to $11) and the Duncan (singles $5 to $6, doubles $8 to $10). Both are in

New Haven near the campus of Yale University. Write to either, saying that you are coming to the meeting of the American Physical Society.

(c) *New motels* are the New Haven Motor Inn and the Rip Van Winkle Motel, both on the Merritt Parkway at exit 59, and the Tremont Motor Courts near the Yale Bowl.

Deadline for abstracts for this meeting is Friday April 27.

Preliminary Announcement of the 1956 Summer Meeting in the West

The summer meeting of the American Physical Society on the West Coast is to be held at the University of Oregon in Eugene, Oregon, on June 21, 22, and 23, 1956. The deadline for contributed papers for this meeting is Friday, the 20th of April. Abstracts are to be sent to Dr. W. A. Nierenberg, University of California, Berkeley 4, California.

Eugene is located on the main line of the Southern Pacific Railway; the "Shasta Daylight" and the "Cascade" are the best trains operated on the San Francisco–Portland run. United Air Lines serve Eugene airport with two northbound and two southbound flights daily. All flights have connections to and from the East, including a new nonstop flight between Portland and Chicago. Limousine service is available between the airport and the Eugene Hotel. By automobile, Eugene is best reached from the south via highways 97 or 99; from the north via highway 99; and from the east over any one of three picturesque passes—Santiam (highway 20), McKenzie (highway 126), and Willamette (highway 97).

Accommodations are available as follows:

(a) *Hotels:* The local committee recommends the Eugene Hotel ($5 to $6 single; $8 double; $9 twin). Lower rates prevail at the Osburn Hotel ($4 to $4.50 single; $5 to $6 double; $6.50 to $7 twin). These hotels will hold a number of rooms for APS members. Reservations should be made at least two weeks in advance of the meeting by writing directly to a hotel, mentioning the APS. A deposit should be sent if arrival after 7 P.M. is anticipated.

(b) *Motels:* A number of good motels exist in the vicinity of the campus. Among them are the Flagstone Motel, 1601 Franklin Boulevard ($6.50 double) and the City Center Lodge, 476 East Broadway ($7 double). A list of other motels in the area has been compiled and is available either at the office of the local secretary or from Dr. Bernd Crasemann, Chairman of the Local Committee.

(c) *Dormitories:* The local committee has reserved 50 accommodations in a University dormitory on campus. The rate will be approximately $3 per person per night, in double rooms. Requests for dormitory reservations should be sent to Dr. Crasemann *before May 21.*

Wanted

The American Physical Society would like to buy the following copies of *The Physical Review* for 1955: January 1, January 15, April 1, and July 1. Payment of $1.50 per copy will be made. Copies should be sent to Mr. Wallace Waterfall, American Institute of Physics, 57 East 55th Street, New York 22, New York.

(**Please keep this page on file!**)

MEETINGS AND DEADLINES FOR THE REMAINDER OF 1956

Place	*Meeting dates*	*Deadline date*
Washington	April 26–28	past
Eugene*	June 21–23	April 20
New Haven	June 21–23	April 27
Chicago	November 23–24	September 21
Monterey,* California	December 27–28–29	October 19

* Abstracts for the Eugene and Monterey meetings are to be sent to W. A. NIERENBERG, University of California, Berkeley 4, California, and must reach his office not later than the corresponding deadline date.

Abstracts for the other meetings listed above are to be sent to KARL K. DARROW, American Physical Society, Columbia University, New York 27, New York, and must reach his office not later than the corresponding deadline date. To avoid chance of confusion, please do not send an abstract for any meeting until the deadline date of the previous meeting is at least five days past. *The privilege of contributing papers to meetings of the American Physical Society is restricted to the members of the Society and to nonmembers whose papers are sponsored by members.*

RULES PRESCRIBED FOR ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten and double-spaced; one must be an original, the other may be an original or a carbon copy. Each abstract must be confined to a single page: if it is too long for a single page it is too long to be printed. *Henceforth, if we receive an abstract typed on two pages, we shall print only its first page.* Write each abstract as a single paragraph: the suppression of paragraphs costs time and labor to the editors. Do not use very thin paper; a sheet of very thin paper may cause extraordinary trouble when mixed with sheets of reasonable thickness. Look at the abstracts in this *Bulletin* to see how the title of the paper and the name of the author are to be arranged, and follow the example. Issues of the *Bulletin* are sometimes appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line. **By action of our Council, abstracts will not henceforth be withdrawn from our proofs unless the asker sends ten dollars with his request.**

EPITOME OF THE 1956 WASHINGTON MEETING

(Personal names are those of invited speakers. NBS stands for National Bureau of Standards, S-P for Sheraton Park Hotel.)

Thursday Morning

A. Zucker, Seaborg, Breit. Shoreham, West Ballroom.
B. Radioactive nuclei, I. S-P, Continental.
C. Coulomb excitation, fission; Wiegand. S-P, Burgundy.
CA. Electron physics. NBS, East.
D. Electron pairs; Telegdi, Berko. Shoreham, Main Ballroom.
DA. Theoretical physics, I: high-energy scattering theory. S-P, Caribar-Mural.

Thursday Afternoon

E. Radioactive nuclei, II. S-P, Continental.
EA. Mesons. Shoreham, Main Ballroom.
F. Neutrons, I. Shoreham, West Ballroom.
FA. McGuire, Schindler, Petritz, Davisson, Plaskett. NBS, East.
G. Apparatus of nuclear physics, I. S-P, Burgundy.
H. Lamb, Kusch; post-deadline papers, if any. S-P, Grand.
HA. Theoretical physics, II: nuclear theory. S-P, Caribar-Mural.

Friday Morning

J. Apparatus of nuclear physics, II. S-P, Burgundy.
JA. *K*-mesons, hyperons, antiprotons. Shoreham, Main Ballroom.
K. Neutrons, II. Shoreham, West Ballroom.
KA. Ferromagnetism and ferroelectricity. NBS, East.
L. Dupouy, Gabor, Marton, Fano. S-P, Grand.
M. Transmutation, I, including scattering. S-P, Continental.
MA. Theoretical physics, III: nuclear theory. S-P, Caribar-Mural.

Friday Afternoon

N. Transmutation and nuclear energy levels, II. NBS, Materials Testing.
NA. Microwaves and bands; x-rays. S-P, Exhibit Hall.
P. Biophysics. S-P, Burgundy.
PA. Chemical physics. Business Meeting of Division of Chemical Physics. Shoreham, West Ballroom.
Q. Solid-state physics, I, including metals. NBS, East.
QA. Tolhoek, Hughes, Friedlander, Occhialini, Barkas. Shoreham, Main Ballroom.
R. Radioactive nuclei, III: isomers, aligned nuclei. S-P, Continental.
RA. Theoretical physics, IV: field theory, strange particles. S-P, Caribar-Mural.

Friday Evening at 7:00

Banquet of the American Physical Society. Presentation of Scott Medal to J. W. Beams. After-dinner speakers. Shoreham, Terrace Room.

Saturday Morning

S. Thomas, Metropolis, Householder, Goldstine. Shoreham, West Ballroom.
SA. Transmutation and nuclear energy levels, III. NBS, Materials Testing.
T. Solid-state physics, II, including alkali halides. S-P, Grand.
TA. Radio-frequency spectroscopy. Shoreham, Main Ballroom.
U. Cryogenics. NBS, East.
UA. Nuclear emulsions; general nuclear physics. S-P, Burgundy.
V. Langsdorf, Hamermesh, Williams, Ferrell, Snell. S-P, Continental.
VA. Theoretical physics, V: statistical mechanics. S-P, Caribar-Mural.

Saturday Afternoon

W. Transmutation and nuclear energy levels, IV. NBS, Materials Testing.
WA. Solid-state physics, III; semiconductors. S-P, Grand.
X. Fluid dynamics; atmospheric physics. S-P, Burgundy.
XA. Brickwedde, Herzfeld. NBS, East.
Y. Cosmic rays. Shoreham, West Ballroom.

PROGRAMME

THURSDAY MORNING AT 10:00

Shoreham, West Ballroom

(R. BERINGER presiding)

Symposium on Transmutation by Heavy-Ion Bombardment

A1. Nuclear Reactions with 26-Mev Nitrogen Ions. ALEXANDER ZUCKER, *Oak Ridge National Laboratory.* (40 min.)

A2. Production of Heavy Nuclides by Heavy-Ion Bombardment. G. T. SEABORG, *University of California, Berkeley.* (40 min.)

A3. Possibilities of Heavy-Ion Bombardment for Nuclear Theory. GREGORY BREIT, *Yale University.* (40 min.)

THURSDAY MORNING AT 10:00

Sheraton Park, Continental Room

(K. WAY presiding)

Radioactive Nuclei, I

B1. Beta Spectrum of Cl^{36}. R. G. JOHNSON, O. E. JOHNSON, AND L. M. LANGER, *Indiana University.**—The twice forbidden beta spectrum of Cl^{36} has been measured with a 4π scintillation spectrometer which is particularly well suited for measuring beta spectrum shapes from low specific activity sources. The scintillation spectrometer has reliably reproduced well known allowed and forbidden spectra. The Cl^{36} spectrum has been measured to as low as 89 kev with three sources of average thicknesses of 9, 19, and 20 $\mu g/cm^2$. Consistent results were obtained for the three sources, and the spectral distributions were in good agreement with the proportional counter measurement of Fulbright and Milton[1] but showed fewer electrons at low energies than the magnetic spectrometer measurements of Wu and Feldman.[2] The best fit to the data in terms of the combination of S and T interactions was obtained for $R_{ij}/T_{ij}=0$ and $A_{ij}/T_{ij}=14.2$. This is equivalent to a best fit for the pure T interaction, but $A_{ij}/T_{ij}=14.2$ is not consistent with $A_{ij}/T_{ij}=5.1$ or $A_{ij}/T_{ij}=4.2$ as found by Fulbright and Milton or Wu and Feldman, respectively, using the low-Z approximation for the pure T interaction. It is found that the low-Z approximation yields a fit for two values of A_{ij}/T_{ij}.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission and by a grant from the Research Corporation.

[1] H. W. Fulbright and J. C. Milton, Phys. Rev. **82**, 274 (1951).

[2] C. S. Wu and L. Feldman, Phys. Rev. **76**, 693 (1949).

B2. Decay of Cl^{39}.* J. R. PENNING, H. R. MALTRUD, J. C. HOPKINS, AND F. H. SCHMIDT, *University of Washington.*—The beta- and gamma-ray spectra of 55.1-min[1] Cl^{39} have been studied with a uniform-field solenoidal beta-ray spectrometer and with stilbene and NaI scintillation spectrometers. The active chlorine was produced by the $A^{40}(\alpha,\alpha p)Cl^{39}$ reaction on argon gas in the University of Washington 60-inch cyclotron. The activity was precipitated as AgCl from washings of the target bell jar. Cl^{38} (37.3 min) which was also produced was allowed to decay until it was a negligible fraction of the chlorine activity. Three gamma rays with energies of 246, 1270, and 1520 kev and relative intensities of 1.0, 1.0, and 0.84, respectively, are found. The 246- and 1270-kev gamma rays are in coincidence with each other and are not in coincidence with the 1520-kev gamma ray. Approximately 5% of the beta transitions take place to the ground state and have an end point of 3.43 Mev. The remaining 95% of the transitions have an end-point energy of 1.90 Mev and are in coincidence with each of the three gamma rays. An upper limit of 2.5×10^{-3} can be set on the total internal conversion coefficient for each of the gamma rays. Work on this isotope is still in progress; the data presented here are tentative.

* Work supported in part by the U. S. Atomic Energy Commission.

[1] Haslam, Katz, Moody, and Skarsgard, Phys. Rev. **80**, 318 (1950).

B3. Chlorine-40.* H. MORINAGA, E. L. ROBINSON, AND E. BLEULER, *Purdue University.*—In order to study the low-lying excited states of A^{40}, the decay of a new radioactive isotope, chlorine-40, produced by a (n,p) reaction with argon, was studied with scintillation spectrometers. The gamma-ray spectrum from a liquid argon target bombarded with fast neutrons shows, in addition to the 1.30-Mev and 3.12-Mev radiations from A^{41} and S^{37}, three gamma rays of 1.46, 2.75, and about 6 Mev decaying with a half-life of 1.4 min. A beta spectrum, decaying with the same half-life, was observed to extend up to ~7 Mev, with strong low-energy component (s). The assignment of this activity to Cl^{40} is based on chemical separations, the high yield, and the agreement of the 1.46-Mev gamma ray with the known transition from the first excited state of A^{40}. The significance of the decay scheme in connection with the systematics of the first odd-parity states in even-even nuclei[1] will be discussed.

* Supported in part by the U. S. Atomic Energy Commission.

[1] H. Morinaga (to be published).

B4. Decay of V^{53} and V^{54}.* A. W. SCHARDT AND B. J. DROPESKY, *Los Alamos Scientific Laboratory.*—Two new radionuclides, V^{53} and V^{54}, have been produced by irradiation of Cr^{53} and Cr^{54} with fast, monoenergetic neutrons, and their radiations have been examined with β and γ scintillation spectrometers. The above assignments were supported by identification of the known activities producible by fast neutron irradiation of the various enriched chromium isotopes. The nuclide V^{53}, $t_{\frac{1}{2}}=2.0\pm0.4$ min, emits β^- rays of 2.50 ± 0.05-Mev maximum energy and 1.00 ± 0.01-Mev gamma rays. The gammas prob-

ably correspond to transitions to the ground state from a previously known[1] 0.97-Mev level in Cr^{53}. An earlier assignment of a 23-hr activity to V^{53} has already been shown to be doubtful.[2] The nuclide V^{54} has a half-life of 55 ± 5 sec; its scintillation β^- spectrum in the >2-Mev region is consistent with one group of 3.3 ± 0.2-Mev end-point energy. Gamma rays of 0.835 ± 0.009, 0.99 ± 0.01, and 2.21 ± 0.04 Mev were also observed. The 0.835- and 0.99-Mev gammas have approximately equal intensity and are in coincidence with each other and with quanta of energy >1.5 Mev. The corresponding energy levels in Cr^{54} are at 0.835 (known from Mn^{54} decay), 1.825, and probably 4.04 Mev.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] McFarland, Bretscher, and Shull, Phys. Rev. **89**, 892 (1953).
[2] Sheline, Wilkinson, Dropesky, and Shull, Phys. Rev. **99**, 1055 (1955).

B5. Beta Spectrum of Co^{56}. J. D. KURBATOV, H. J. SATHOFF, JR.,* K. HISATAKE, AND M. SAKAI,† *The Ohio State University.*—Carrier free Co^{56} was separated from enriched Fe^{56} which had been activated with protons. The positron spectrum of Co^{56} was obtained on a magnetic lens spectrometer using several different samples of varying weights. For the thinnest samples, about 6μg, the Fermi plot was a straight line in the energy interval from 320 kev to 1.47 Mev. The recently reported[1] second positron spectrum of 0.977 Mev u.e.l. and the provisionally reported[2] 0.440 Mev u.e.l. were not observed, that is, within an exactness of better than 2% of the positron decay of $1.47\pm.03$ Mev. A disintegration scheme will be discussed and the procedure for isolation of carrier free Co^{56} will be presented.

* Lieutenant, United States Air Force, on tour of duty, Ohio State University, 1954–1955.
† At present at Institute of Nuclear Studies, University of Tokyo.
[1] K. P. Howard *et al*, Nuclear level schemes, TID-5300 (June 1955).
[2] M. Sakai *et al.*, Phys. Rev. **95**, 101 (1954).

B6. Decay of Co^{58}.* A. ROSSI,† H. FRAUENFELDER, N. LEVINE, AND SIDNEY SINGER, *University of Illinois.*—Co^{58} is known to decay to the first excited state of Fe^{58} ($E=0.81$ Mev). Recently, McFarland *et al*[1] established the existence of the second excited state of Fe^{58} at about 1.62 Mev. Energetically, Co^{58} can decay into this state also and we searched for corresponding gamma lines. The expected transition from the second to the first excited state could not be observed directly because its energy is very close to that of the intense 0.81-Mev gamma ray. By coincidence measurements, however, we found its intensity to be 0.016 ± 0.006, relative to that of the main 0.81-Mev gamma ray. The directional correlation between the two 0.81-Mev gamma rays uniquely assigns spin 2 to the first and second excited states of Fe^{58} and shows that the 2–2 transition is a mixture of $E2$ and $M1$, with $\delta(E2/M1)=+2.2\pm0.3$. The 1.62-Mev crossover transition was also observed. Its intensity was found to be 0.005 ± 0.001, in agreement with the recent measurement of Robinson and Fink.[2]

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Research Fellow under the U. S. Exchange Program; on leave from the University of Milan, Italy.
[1] McFarland, Shull, Elwyn, and Zeidman, in "Nuclear level schemes," U. S. Atomic Energy Commission, TID-5300, (June, 1955).
[2] Robinson and Fink, Bull. Am. Phys. Soc. Series II, 1, No. 1, 40 (1956).

B7. Positron Decay of Cu^{59}.* F. W. PROSSER, JR., M. S. MOORE, AND J. P. SCHIFFER, *The Rice Institute.*—The positron decay of Cu^{59} has been investigated by the measurement of the positron spectrum in a flat-sector, shaped pole-face electron spectrometer and of the γ-ray spectrum with a scintillation spectrometer. The sources were prepared by bombardment of natural Ni foils with 4-Mev deuterons. The half-life for emission of positrons above 1.45 Mev was found to be 83 ± 1 sec, but at 0.70 Mev contained a strong contribution from longer half-lives. These same half-lives were seen in the yield of annihilation quanta. The end-point energy was found to be 3.74 ± 0.10 Mev. The log ft value is 5.0. The γ-ray energies found were 0.87, 1.28, 1.68, and 2.06 Mev, all $\pm2.5\%$. In addition, there appear to be at least two γ rays with energy less than 0.5 Mev. The half-lives of the 0.87-, 1.28-, and 1.68-Mev γ rays are in agreement with the 83 sec found for the higher energy positrons. The 0.87- and 1.28-Mev γ rays are of approximately equal intensity and, if in cascade, account for about 5–10% of the decays. Coincidence studies are in progress to determine the levels involved in Ni^{59}.

* Supported in part by the U. S. Atomic Energy Commission.

B8. Beta Decay of Cu^{59}. J. W. BUTLER, C. R. GOSSETT, AND H. D. HOLMGREN, *Naval Research Laboratory.*—Cu^{59} has been produced by bombarding Ni^{58} with protons of 1.84 Mev. Cu^{59} has an 81-second positron activity which leaves Ni^{59} in one of several excited states. The gammas emitted in the decay of these states have been measured with NaI crystals and conventional pulse-measuring equipment. The energies are 1.80, 1.31, 0.87, 0.35, and 0.19 Mev. The indication for the lowest energy gamma is weak, possibly because of a high internal conversion coefficient. Coincidence experiments have been performed to determine the cascade scheme. A level sequence will be proposed.

B9. Decay of Nb^{90}. N. H. LAZAR AND G. D. O'KELLEY, *Oak Ridge National Laboratory.*—The gamma and beta radiations from the decay of Nb^{90} have been studied with single crystal and coincidence scintillation spectrometers. Gamma rays of 2.32 ± 0.02, 2.19, 1.96, 1.82, 1.14, and 0.14 Mev were identified from an analysis of the pulse-height spectrum obtained with a 3-inch high, 3-inch diameter NaI crystal, and their relative intensities were determined. The maximum energy positron component measured with an anthracene spectrometer had an end-point energy of 1.51 ± 0.03 Mev, and appeared to be in coincidence with the 1.14-Mev gamma ray. The 2.32-Mev transition was not found in coincidence with any of the other radiations, but the 2.19-Mev gamma ray was found in coincidence with a window set over the 0.14-Mev region. Data obtained in coincidence with all the other major peaks will be discussed with reference to the 0.8 second, 2.32-Mev isomeric transition[1] and the 0^+ level at 1.75 Mev[2] which also occur in Zr^{90}.

[1] Campbell, Peelle, Maienschein, and Stelson, Phys. Rev. **98**, 1172(A (1955).
[2] Johnson, Johnson, and Langer, Phys. Rev. **98**, 1517 (1955).

B10. Decay of Eu^{152} and Eu^{152m}. I. L. GRODZINS, *Brookhaven National Laboratory.**—Both the 13-yr ground state and the 9-hr isomeric state of Eu^{152} decay by K-capture to Sm^{152}, and by beta emission to Gd^{152}. From Eu^{152} the following gamma rays (kev) and their relative intensities (percent per disintegration) are found to be transitions in Sm^{152}: 122(57), 244(6.7), 871(4), 967(12.5), 1089(11.0), 1410(21). The 244, 967, and 1410 transitions end at the 122 kev first excited state. The 1089-kev γ ray is a crossover to the ground state. The 871-kev transition ends at the 366-kev second excited state. The principal γ transitions in Gd^{152} and their intensities are 344(33), 411(1), 784(14). The 411- and 784-kev γ rays end at the 344-kev first excited state of Gd^{152}. Following the decay of Eu^{152m}, γ rays in Sm^{152} are: 122, 854, 976, and 1410 kev. The 854- and 1410-kev transitions end at the first excited state; the 976-kev is a transition to the ground state. Predominant γ rays in Gd^{152} from Eu^{152m} are 344, 983, 1300, and 1327 kev. The 983 and 1300 kev lead to the first excited state; the 1327 kev is a crossover to the ground state. The position of several weaker transitions in the decays of Eu^{152} and Eu^{152m} will be discussed.

* Under the auspices of the U. S. Atomic Energy Commission.

B11. Decay of Eu^{152} and Eu^{152m}. II. H. KENDALL* AND L. GRODZINS, *Brookhaven National Laboratory.*†—Scintillation counter studies of 344-kev $\gamma\beta$ coincidences together with β spectrometer measurements of the β spectra of both Eu^{152} and Eu^{152m} yield an energy difference between the ground states of Eu^{152} and Gd^{152} of 1790 kev. The energy difference between the 9-hr isomeric state and the ground state in Eu^{152} can be deduced to be 80 ± 25 kev. The positron spectrum from Eu^{152m} was detected in an anthracene crystal in coincidence with two NaI(Tl) side crystals channeled on annihilation radiation. From this an energy difference between the ground states of Eu^{152} and Sm^{152} of 1740 ± 100 kev was obtained. These measurements together with the decay scheme information (preceding abstract) determine the ft values of the K-capture and beta transition of Eu^{152}. Angular correlation and absolute K-conversion measurements of the 344- to 784-kev cascade in Gd^{152} indicate that the 1128-kev level is $3-$. The spin and parity of the 755-kev second excited state in Gd^{152} is being investigated.

* National Science Foundation postdoctoral fellow.
† Under the auspices of the U. S. Atomic Energy Commission.

B12. Radiations from Eu^{155} and Sm^{153}.* V. S. DUBEY,† C. E. MANDEVILLE, AND M. A. ROTHMAN, *Bartol Research Foundation.*—Using coincident scintillation spectrometers employing single-channel analysis as well as a slow-fast circuit incorporating a 20-channel analyzer, the radiations of Eu^{155} and Sm^{153} have been investigated. Eu^{155} is found to decay with emission of two beta spectra having end points at 240 kev (79%) and 150 kev (21%). A gamma ray was detected at 102 kev. An 84-kev to 18-kev cascade is also present. The harder beta spectrum is noncoincident with gamma radiation. All beta-gamma coincidences observable at beta-ray energies greater than 150 kev are attributed to the presence of $Eu^{152, 154}$. The beta spectra of Sm^{153} are found to have end point energies of 825, 720, 645, and 130 kev and relative intensities of 27, 32, 40, and ~0.06. The gamma rays of Sm^{153} have quantum energies of 70, 100, 170, 530, and 600 kev. The relative intensities of the transitions associated with these gamma rays are, when corrections are introduced to take into account internal conversion, 0.68, 1.0, 4.5×10^{-4}, 6.5×10^{-4}, and 1.5×10^{-4}. Disintegration schemes will be presented.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† On leave of absence from Agra College, Agra, India.

THURSDAY MORNING AT 10:00

Sheraton Park, Burgundy Room

(N. P. HEYDENBURG presiding)

Coulomb Excitation, Fission

C1. Angular Distribution of Gamma Rays Following Coulomb Excitation in Pt^{194}, Cd^{114}, Pd^{110}, Ru^{104}, Cd^{113}, and Cd^{111}. F. K. MCGOWAN, P. H. STELSON, AND M. M. BRETSCHER,* *Oak Ridge National Laboratory.*—The angular distributions of gamma rays with respect to the incident proton beam on thick targets have been measured for gamma rays following Coulomb excitation in Pt^{194} 330-kev, Cd^{114} 555-kev, Pd^{110} 374-kev, Ru^{104} 358-kev, Cd^{113} 582-kev, and Cd^{111} 610-kev. Metallic targets of the enriched isotopes were prepared either by electrodeposition onto nickel or by sintering metallic powders into thin foils. Thick target energy dependent coefficients a_ν, including a correction for multiple Rutherford scattering, have been evaluated by use of the numerical results[1-3] obtained from a quantum-mechanical treatment of the Coulomb excitation process. The energy dependent coefficients a_ν for a thick target deduced from the measurements in even-even nuclei agree with the numerical results in every case. The angular distribution measurements lead to a transition assignment of 5/2 $(E2)$ in Cd^{113} and Cd^{111}.

* Research participant for the summer of 1955 from Alabama Polytechnic Institute.
[1] Goldstein, McHale, Thaler, and Biedenharn, Phys. Rev. **100**, 436 (1955); Biedenharn, Goldstein, McHale, and Thaler, Phys. Rev. (to be published).
[2] Breit, Ebel, and Benedict, Phys. Rev. **100**, 429 (1955); Benedict and Tice, Phys. Rev. **100**, 1545 (1955).
[3] Alder and Winther, Danske Math.-fys. Medd. **29**, No. 19 (1955).

C2. Polarization of Gamma Rays Following Coulomb Excitation. P. H. STELSON AND F. K. MCGOWAN, *Oak Ridge National Laboratory.*—Coulomb excitation of levels in odd-A nuclei frequently results in the emission of mixed $E2+M1$ γ rays. An angular distribution measurement gives information on $E2/M1$ and this combined with the cross section for excitation yields the reduced transition probability for the magnetic dipole transition, $B(M1)/(eh/2mc)^2$. However, several cases have been encountered in which the angular distribution was equally well fitted by two rather different values for $E2/M1$. Calculations of the expected polarization of the γ rays showed that this property was quite different for the two values of $E2/M1$. A polarimeter based on the Compton scattering mechanism has been constructed and its effectiveness determined by measurements of the known polarization of γ rays from excitation of 2^+ levels in even-even nuclei. Five transitions of the type $\frac{3}{2}(E2+M1)\frac{1}{2}$ in which a polarization measurement has resolved the ambiguity in the $E2/M1$ value are summarized in Table I. P is $W(90°,90°)/W(90°,0°)$ in the notation of Biedenharn and Rose.

TABLE I.

Nucleus	E_γ(kev)	$(E2/M1)^\frac{1}{2}$	$P_{calculated}$	$P_{Measured}$	$B(M1)/(eh/2mc)^2$
$Ag^{107,109}$	315	−0.18 or −1.2	0.71 or 1.42	0.68±.04	2.6×10^{-1}
Rh^{103}	305	−0.18 or −1.2	0.71 or 1.43	0.71±.04	2.1×10^{-1}
Cd^{113}	300	+0.29 or −4.0	0.54 or 1.86	0.57±.05	3.8×10^{-2}
Cd^{111}	342	+0.39 or −6.6	0.51 or 1.97	0.56±.04	2.7×10^{-2}

C3. Coulomb Excitation of V^{50}, Kr, Xe, Te, and Eu^{151}. N. P. HEYDENBURG AND G. M. TEMMER, *DTM, Carnegie Institution of Washington.*—Excitation of a target enriched in the odd-odd isotope V^{50} has revealed a gamma ray of 225 kev, corresponding to an excited state at that energy. By bombarding a small gas cell containing ordinary krypton and xenon with 6.5 Mev alphas we have been able to observe the de-excitation gamma spectra of these elements. We see the gamma rays associated with the 0^+-2^+ transitions in several of the more abundant even-even isotopes; a 457-kev transition is assigned to Kr^{82}, while lines at 286 and 364 kev probably belong to Xe^{131}. All six even-even isotopes of tellurium were examined with enriched targets[1] and yielded the following first-excited state (0^+-2^+) transitions (*in kev*): Te^{120}-*560*; Te^{122}-*570*; Te^{124}-

608; Te^{128}-*662*; Te^{128}-*750*; Te^{130}-*850*. Their reduced *E2* transition probabilities will be presented. Finally, we examined separated isotopes of Eu^{151} ($N=88$) and Eu^{153} ($N=90$) to confirm our assumptions[2] concerning the rotational level scheme in the latter. We find levels in Eu^{151} at 190 and 303 kev (not a rotational band for spin 5/2). Eu^{153}, however, has a well-developed rotational sequence.[2] In the ordinary Eu target the 190-kev gamma ray in Eu^{151} was unresolved from the second rotational state crossover transition in Eu^{153}. The effects of this correction will be discussed.

[1] Isotopes courtesy of Oak Ridge National Laboratory.
[2] N. P. Heydenburg and G. M. Temmer, Phys. Rev. **100**, 150 (1955); G. M. Temmer and N. P. Heydenburg, Bull. Am. Phys. Soc. Ser. II, **1**, 43 (1956).

C4. Coulomb Excitation of V, Ni, Ga, Rb, and Sn. L. W. FAGG, E. H. GEER, AND E. A. WOLICKI, *Naval Research Laboratory*.—Studies have been made of the gamma ray spectra of isotopically enriched V^{50}, Ni^{61}, Sn^{115}, Sn^{117}, and Sn^{119}, and natural Ga and Rb when bombarded by four- to five-Mev alpha particles from the Naval Research Laboratory 5-Mv Van de Graaff generator. The spectra were examined with a two-inch NaI spectrometer whose energy and efficiency were calibrated with standard sources. The following gamma rays have been observed: V^{50}, 228 kev;[1] Ni^{61}, 67, 282, and 645 kev; Ga, 324 and 513 kev; Rb, 150 and 407 kev.[1] The 324- and 513-kev radiations from Ga have been tentatively assigned to Ga^{69} and Ga^{71}, respectively. Similarly, the 150- and 407-kev radiations in Rb probably arise from Rb^{85} and Rb^{87}, respectively. Bombardment of the enriched odd isotopes of tin produced no observable gamma rays. Measurements of the reduced transition probabilities for excitation will be presented.

[1] Heydenburg and Temmer have also measured gamma rays at 228 kev in V^{50} and at 150 kev in Rb^{85} (private communication).

C5. Energy Dependence of ν for Pu^{239}.* L. M. BOLLINGER, R. E. COTÉ, P. HUBERT,† J. M. LEBLANC, AND G. E. THOMAS, *Argonne National Laboratory*.—Recent experiments[1] seemed to show that ν, the number of neutrons per fission, decreased by 12% between 0.025 and 0.3 ev for Pu^{239}. To check the possibility that ν varies from resonance to resonance, we have used the Argonne fast chopper to measure relative values of ν for all resolvable resonances. The measurements were made by comparing counting rates in a Pu fission chamber containing 120 mg of Pu with rates of threefold coincidences between this chamber and two large liquid scintillation detectors used so as to respond primarily to fission neutrons; the ratio of these rates is roughly proportional to ν^2. Systematic errors were minimized by simultaneously recording both rates as a function of flight time in a 1024-channel time analyzer. In the energy range from 0.02 to 0.5 ev, ν is found to be constant within a standard statistical error of ½%. At higher energies, 8 individual resonances and 4 additional groups of resonances are resolved. Examination of ½ of the data obtained shows that, within an average statistical accuracy of 6%, ν is the same for all resonances.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† When on leave from Saclay Laboratory.
[1] Zimmerman, Palevsky, Hughes, Bull. Am. Phys. Soc., Series II, 1, 8 (1956).

C6. Angular Distribution of Fragments from the 450-Mev Proton-Induced Fission of Bismuth.* R. L. WOLKE, *University of Chicago*.—The angular distribution of selected fission fragments from the 450-Mev proton bombardment of bismuth have been measured by a recoil-catching technique which has been previously described.[1] The laboratory distribution of Sr^{91-92} (representing symmetric fission of Bi) was analyzed into a forward motion of the fissioning nucleus along the direction of the proton beam, and a distribution in the system of the fissioning nucleus of the form $a+b\cos^2\theta'$, where θ' is the angle between the proton direction and the fragment in the fissioning-nucleus system. b/a was calculated to be 0.13. The $a+b\cos^2\theta'$ distribution is the same form as that observed from the 22-Mev proton-induced fission of thorium,[2] with a comparable value of b/a. Results of measurements on asymmetric fission fragments from Bi will also be presented.

* Supported in part by a grant from the U. S. Atomic Energy Commission.
[1] R. L. Wolke, Phys. Rev. **98**, 1199 (1955).
[2] Cohen, Jones, McCormick, and Ferrell, Phys. Rev. **94**, 625 (1954).

Invited Paper

C7. Recent Work on the Antiproton. C. E. WIEGAND, *University of California, Berkeley*. (30 min.)

THURSDAY MORNING AT 10:00

NBS, East Building

(E. A. COOMES presiding)

Electron Physics

CA1. A Collective Description of Electron Interaction in Solids. PHILIPPE NOZIÈRES AND DAVID PINES, *Princeton University*.—The interaction between valence electrons in solids has been investigated by methods closely related to those used by Bohm and Pines for the free electron gas. The long-range interaction between electrons may be described in terms of plasma waves of frequency $\omega_0=(4\pi ne^2/m)^{\frac{1}{2}}$, where n is the valence electron density, m the free-electron mass. The influence of the periodic potential of the ion cores appears only through the coupling of the plasma waves with the individual valence electrons. This interaction is studied by using a canonical transformation defined in terms of appropriate electron Bloch waves. The resultant Hamiltonian is equivalent to that found by Kanazawa.[1] It describes independent plasma waves, with a dispersion relation identical with that proposed by Mott,[2] and electrons whose effective interaction is screened. The effect of the short-range interaction between the electrons on the plasma frequency has been investigated, and is small for the cases of principal interest. The effective electron interaction in solids will be discussed on the basis of this model.

[1] H. Kanazawa, Progr. Theoret. Phys. (Japan) **13**, 227 (1955).
[2] N. F. Mott, Proc. Tenth Solvay Congress, Bruxelles (1954).

CA2. Electron Interaction in Solids. DAVID PINES AND PHILIPPE NOZIÈRES, *Princeton University*.—The methods and

Hamiltonian developed in the preceding abstract may be applied to a number of problems in solids for which electron interactions are of importance. These include characteristic energy losses, dielectric constant and optical properties, and the correlation energy contribution to the cohesive energy. We here restrict our attention to those solids for which the electronic energy differences of importance (whether between electrons in the same or different bands) are small compared to the valence electron plasma energy, $\hbar\omega_0$. In such cases the valence electron plasma is weakly coupled to the individual electron motion, so that the effective plasma frequency is very nearly ω_0. This should be the case for a large number of solids (e.g., Be, Mg, Al, Si, Ge), and the results of experiments on characteristic energy losses are in accord with our expectations. The dielectric constant for such solids may be derived from first principles. The limits of validity of the usual simple expressions and the importance of local field corrections are then obtained, and the optical properties follow in a natural way. Finally, the departure of the electron correlation energy from the free-electron value will be discussed.

CA3. Partition Function and Effective Ionization Potential of an Atom in a Plasma. W. WEIZEL AND G. ECKER.—Analysis of a plasma demands knowledge of the partition function and the effective ionization potential of an atom in a plasma. Therefore, an adequate theoretical calculation of these parameters is very desirable. This is particularly true for the ionization potential, where the experimental results show great discrepancies. However earlier attempts to settle the divergence difficulty of the partition function were based on insufficient assumptions or gave a very crude limitation of the principal quantum number. As for the reduction of the ionization potential, there has been only one rough estimation previously. Our calculation including the interaction with the plasma charge carriers produces a strong limitation on the principal quantum number. The limiting term is essentially a function of temperature and carrier density. The numerical evaluation of the partition function is thus possible with sufficient accuracy. A thermodynamical calculation of the ionization potential including Debye-shielding and the microfield gives also the reduction of the normal ionization energy as a function of temperature and carrier density. The theoretical results lie within the experimental measurements. However, a conclusive comparison with experiments is impossible because of the great uncertainty of the experimental results.

CA4. On the Limitation of the Collective Description of Particle Systems. G. ECKER.—The description of a system of interacting particles requires the formulation of two problems: first, the internal interaction, and second, the dynamical equations. The formulation of the internal interaction is generally either based on the model of binary collisions or—in case of predominating long range interactions—on Vlasov's model of the "smeared-out charge." Usually Boltzmann's equation—or derived relations—are used for the description of the dynamical behavior of the system. A consideration[1] of the collective description based on Vlasov's model and the Boltzmann equation, shows that certain regions of the phase space must be excluded from the application of collective methods. The location of these regions—which we call individual zones—depends on the properties of the whole system as well as on the properties of the single individual. There are different individual zones for the formulation of interaction, and the description of the dynamical behavior. The subdivision of the phase space into individual and collective regions depends also on the process under consideration and hence upon the time. Various conclusions concerning the collision concept, Vlasov's model, and the application of Boltzmann's equation in the description of electron-ion ensembles can be derived.

[1] G. Ecker, Z. Physik **140**, 274 (1955); *ibid.* **141**, 294 (1955).

CA5. Boundary Effects in "Plasma" Losses of Electrons in Thin Films. R. H. RITCHIE, *Oak Ridge National Laboratory.*—Recent work[1] on the determination of the mean free path for "discrete" energy loss of electrons in thin metal foils compares experimental results with theoretical predictions of the energy loss.[2] The transient electrodynamic disturbance created by the passage of an electron through the boundaries of a thin foil gives rise to an energy loss which is not included in conventional formulations. A formula has been derived for this "transient" loss in the case of a relativistic charged particle incident on a foil having a dielectric constant $\epsilon(\omega)$. It is shown that for plasma this effect may be neglected only if the foil thickness is much greater than v/Ω, where v is the particle velocity and Ω is the "plasma" frequency. Since v/Ω is of the order of hundreds of Angstroms for relativistic electrons in certain metals, measurements of the kind described in reference 1 may show this effect.

[1] Blackstock, Ritchie, and Birkhoff, Phys. Rev. **100**, 1078 (1955).
[2] D. Pines and D. Bohm, Phys. Rev. **85**, 338 (1952).

CA6. Plasma Streams.* WINSTON H. BOSTICK, *University of California, Livermore,*† AND DAVID FINKELSTEIN,‡ *Stevens Institute of Technology and New York University.*—Spark sources of plasma streams will be described with which magnetohydrodynamic experiments have been done. Pictures and measurements will be shown of such effects as plasma diamagnetism, magnetic collimation of plasma streams, electric polarization of plasma streaming across a magnetic field, and the interactions of colliding plasma streams.

* Supported by the U. S. Atomic Energy Commission.
† On leave of absence from Tufts University.
‡ The second author wishes to thank the Arc Research staff at Livermore for their hospitality in the Summer of 1955, during which he participated in this work.

CA7. The Classical Partition Function For Ions in a Plasma.* A. A. BROYLES, *The RAND Corporation.*—Methods[1] employing collective coordinates have been worked out for dealing with a plasma made up of ions moving in a uniform negative sea of electrons. These methods are applied here to the approximate evaluation of the classical partition function. This requires the evaluation of the configurational integral. All configurations are properly handled where the particles are separated by a distance greater than a critical distance r_e which is about two-thirds the ion sphere radius. Corrections are made for configurations where clusters of only two ions exist that are within a distance r_e of each other. Comparisons are made with previous theories.

* This work was supported by the U. S. Atomic Energy Commission.
[1] A. A. Broyles, Bull. Am. Phys. Soc. Series II, 1, No. 1, 27 (1956).

CA8. Electron Energy Losses in Pb and the Compounds PbS, PbSe and PbTe. LEWIS B. LEDER, *National Bureau of Standards.**—Previously[1] we reported that the characteristic energy losses of electrons in several metals and the oxides or sulfides of these metals appeared to be the same except for a small upward shift of the energy loss in the case of the compound. The same effect is found for the materials Pb, PbS, PbSe, and PbTe. In the earlier work the intensity relationships were unreliable because they were recorded photographically, but in the present work a photomultiplier detector system was used, and we can see accurately how the characteristic energy losses change both in energy and intensity. In addition to the above-mentioned materials we also measured, for comparison, the loss spectra in $Pb(OH)_2$, Se, and Te. The $Pb(OH)_2$ spectrum shows greater changes from the lead spectrum than to those of the compounds, while the Se and Te spectra appear to be obviously different from the PbSe and PbTe spectra.

* This work was supported in part by U. S. Atomic Energy Commission.
[1] L. B. Leder and L. Marton, Phys. Rev. **95**, 1345 (1954).

CA9. A Field Emission X-Ray Projection Microscope.* R. A. SCHRACK, R. C. PLACIOUS, AND L. MARTON, *National Bureau of Standards.*—Electrons from a field emission source are focused by an electron optical system to a small spot to produce a small bremsstrahlung source for x-ray projection microscopy. A fine tungsten point is operated as a field emission source at elevated temperature, termed *T–F* emission by Dyke and his collaborators.[1] The elevated temperature maintains a clean tungsten surface in a dynamic vacuum system operating at a pressure of 2×10^{-7} mm Hg. The voltage supply is pulsed 60 cps with a ten percent duty cycle. The pulse current is about 100 microamps for 10-kv pulse voltage. About 3×10^{-3} of the total current is focused to a spot to produce x-rays. Exposure time for a density of 1 is about 10 minutes for the above current and voltage and fast no-screen x-ray film without cover. Details on target and resolution will be presented.

* This work supported by The Office of Scientific Research, Air Research and Development Command.
[1] W. P. Dyke *et al.*, Phys. Rev. **95**, 327 (1954).

CA10. On the Possibility of Polarized Field Emission. F. W. LIPPS, *Syracuse University.*—Because of the high current densities which can be achieved at the surface of field emitters, the associated magnetic fields are large and might be sufficient to polarize the electron emission. The transmission function for the metallic surface is independent of H, but the electron distributions are modified and the effect is expressible in terms of a spin dependent work function.

$$\chi_{-}{}^{+}=\chi_{H=0}\pm 2\mu_B H.$$

A discussion of some possible experiments will be given.

CA11. A Columbium-Nickel Matrix Cathode. ARMAND P. LAROCQUE, *Philco Corporation* (introduced by J. F. Barnett).—A new type matrix cathode, named the *P*-cathode, consisting of carbonyl nickel and columbium metal powders mixed with barium-strontium-calcium carbonates, is described. These materials are mixed, pressed at various pressures to achieve a range of porosities, and sintered in dissociated ammonia. The completed disks are assembled in a structure similar to a CR tube cathode and mounted as a planar diode on an octal stem in a *T*–9 bulb. Emission, over a range of temperatures, is measured using a dc method. The logarithm of the emission density is plotted as a function of applied field and is shown to be inversely related to the forming pressure. Emission density is plotted as a function of temperature and the *P*-cathode is shown to be intermediate between the standard oxide cathode and the *L*-cathode[1] and quite similar to the nickel matrix[2] and the bariated nickel[3] cathodes.

[1] R. Levi, J. Appl. Phys. **24**, 233 (1953).
[2] Balas, Dempsey, and Rexer, J. Appl. Phys. **26**, 1163–1165 (1955).
[3] Beck, Brisbane, Cutting, and King, Le Vide, No. 54, 302 (November, 1954).

THURSDAY MORNING AT 10:00

Shoreham, Main Ballroom

(M. DEUTSCH presiding)

Electron Pairs

D1. A Measurement of the Electron Pair Production Cross Section in Lead.* T. L. JENKINS,† *Cornell University.*—The absolute cross section for electron pair production in lead at 1.12 Mev, 1.33 Mev, and 2.75 Mev has been determined. Detection of the pairs was accomplished by detecting the annihilation radiation of the positron with two scintillation counters. The calibration of this detection system and the method of measuring the photon beam incident upon the target will be described. The cross sections measured at the two higher energies are in reasonable agreement with previous results. The cross section at 1.12 Mev was found to be 1.8 $\pm$0.2 times the value predicted by the Bethe-Heitler formula.

* A portion of this work was performed while the author held a National Science Foundation Fellowship.
† Now at University of California Radiation Laboratory, Livermore, California.

D2. Large-Angle Electron Pair Production in Lead.* R. C. MILLER AND C. S. ROBINSON, *University of Illinois.*—Measurements have been made of the energy and angle distribution of electrons and positrons emitted into large angles by a lead target irradiated with 280-Mev bremsstrahlung. A double-focusing magnet was used to select electrons or positrons of known energies from 50 to 170 Mev, which were then counted with a telescope of two scintillators and a water Čerenkov counter. For a 6-mil lead target, data were obtained at 22.5°, 30°, 45°, 60°, and 75°; for 1-, 3-, and 13-mil lead targets at 30° and 60°; and for a 75-mil aluminum target at 30°. At each condition, direct comparison was made of positron and electron counting rates. Large-angle pair particles can be distinguished from pair particles, produced at 0° and scattered into a large angle, by the dependence of counting rate on target thickness. The experimental angular distributions and positron/electron ratios will be presented.

* Supported in part by the Office of Naval Research, U. S. Atomic Energy Commission, and the National Science Foundation.

D3. Mean Free Path for Trident Production by 312-Mev Electrons.* STANLEY L. LEONARD, *Principia College.*—A measurement of the mean free path in nuclear emulsion for direct production of electron pairs by electrons has been made. Stacks of Ilford *G*–5 nuclear emulsion pellicles were exposed to 400-Mev electrons from the Stanford linear accelerator. After processing, these emulsions have been microscopically examined for tridents (direct pair production events) under fairly high magnification, using a track following technique. To date, 42 tridents have been found in 4827 cm of electron track, giving an uncorrected mean free path of 115$\pm$18 cm (the errors being statistical). The electron energy in the scanned region of the emulsion was 312$\pm$30 Mev. Corrections will be made for systematic errors, including a correction for pseudotridents (photon-created pairs lying so close to the parent electron track as to look like tridents). The corrected experimental value will be compared with the theoretical value, 194(−5, +20) cm, calculated from the equations of Racah,[1] the uncertainty resulting from the uncertainty in electron energy.

* Supported by a National Science Foundation research grant.
[1] G. Racah, Nuovo cimento **14**, 93 (1937).

D4. Single-Quantum Annihilation of Positrons.* J. A. WHALEN, *Washington University.*—Positrons emitted from Na^{22} and energy selected by a thin-lens beta-ray spectrometer

impinge upon and stop in a 107-mg/cm² Pb foil. A 2-in. thick NaI(Tl) scintillation crystal detects the single-quantum annihilation photons, and a 1-mm thick NaI(Tl) crystal directly behind the stopping foil detects $K\alpha$ x-rays which follow the annihilation of K-shell electrons in the Pb. A single-quantum annihilation event appears as a coincidence between the outputs of the two scintillation spectrometers, both of which employ differential energy discrimination. Substitution of Al foil as the positron stopper affords the measurement of the background coincidence rate. The results for Pb agree with the theoretical prediction of Jaeger and Hulme.[1] The study of the effect in U indicates the expected Z^5 dependence of the cross section.

* Supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] J. C. Jaeger and H. R. Hulme, Proc. Cambridge Phil. Soc. **32**, 158 (1936).

D5. Narrow Components in the Angular Correlation between Annihilation Quanta from Gases.* MILTON HEINBERG AND LORNE A. PAGE, *University of Pittsburgh.*—The small-angle experiments[1] have been extended to gaseous annihilators. At 17 and 28 atmos argon shows no narrow component at zero magnetic field, but develops one comprising about 11% of the total annihilations at 10 kilogauss. The field dependence is quantitatively that for quenching of the triplet $m=0$ states[2] of positronium, at 28 atmos with slit width of 0.85 milliradian. The width at half-maximum of the total angular correlation goes from 8.1 to 3.8 milliradians. Thus, positronium appears to be formed with kinetic energy of 1 or 2 ev which is retained for at least 10^{-10} sec and is degraded to about 0.3 ev in less than 5×10^{-9} sec. Electric field effects will be discussed. At zero field and 28 atmos, the addition of 0.05% nitrous oxide produces about 3% narrow component while 60 times this amount destroys it. With the 3% nitrous oxide, the angular correlation is magnetically sensitive from 28 to 1 atmos. Oxygen at 26 atmos has the same angular correlation at 10 kilogauss as at zero field, having a broad component and a strong narrow one in nearly equal amounts. The respective widths are 14 and 2.5 milliradians at the stated slit width.

* Part of the Ph.D. thesis of M. H. Work done in the Sarah Mellon Scaife Radiation Laboratory and supported by the Office of Ordnance Research, U. S. Army.
[1] Page, Heinberg, Wallace and Trout, Phys. Rev. **98**, 206 (1955); **99**, 665 (A) (1955); L. A. Page and M. Heinberg, Phys. Rev. (to be published).
[2] M. Deutsch and E. Dulit, Phys. Rev. **84**, 601 (1951); T. A. Pond and R. H. Dicke, Phys. Rev. **85**, 489 (1952).

Invited Papers

D6. Magnetic Quenching of Positron Annihilation in Solids. V. L. TELEGDI, *University of Chicago.* (30 min.)

D7. Positron Annihilation Lifetimes in Solids and Liquids. S. BERKO, *University of Virginia.* (30 min.)

THURSDAY MORNING AT 10:00

Sheraton Park, Caribar-Mural Room

(L. L. FOLDY presiding)

Theoretical Physics, I: High-Energy Scattering Theory

DA1. Theory of *S*-Wave Photopion Production from Protons.* J. ENOCH, *University of Wisconsin,* AND R. G. SACHS,† *Princeton University.*—An analysis of photopion production is based on a suggested[1] resonance theory of pion-nucleon scattering. Contributions to the transition amplitudes arise from direct photoejection, photoexcitation of resonance states, and other, negligible, virtual processes. An estimate of the direct production of S-waves on the basis of the generalized Siegert theorem[2] indicates a rapid decrease of cross section with energy for $E_\gamma > 230$ Mev, in contradiction to experiment.[3] Applicability of the Siegert theorem for photon wavelengths long compared to the source size is verified by a weak coupling calculation with gauge-invariant finite source.[4] It is concluded that the high-energy contributions may result from photoexcitation of the S-wave, $I=\frac{1}{2}$ resonance suggested by analysis of the scattering. Then the S-wave π^0 production should have just $\frac{1}{9}$ the cross section of the S-wave π^+ production at high energy.

* Supported by the U. S. Atomic Energy Commission and Wisconsin Alumni Research Foundation.
† On leave from the University of Wisconsin.
[1] R. G. Sachs, Phys. Rev. **95**, 1065 (1954).
[2] R. H. Capps, Phys. Rev. **99**, 926 (1955).
[3] Keck, Walker, Tollestrup, and Watson (to be published).
[4] R. H. Capps and W. G. Holladay, Phys. Rev. **99**, 931 (1955).

DA2. Chew-Low Treatment of *S*-Wave Mesons.* S. D. DRELL, M. H. FRIEDMAN, AND F. ZACHARIASEN, *MIT.*—A fixed source analysis of S-wave meson scattering has been constructed along the lines of the Chew-Low-Wick formalism. A bilinear S-wave interaction of the form $\lambda_0\varphi^2+\lambda\tau\cdot\varphi\times\pi$ is added to the usual P-wave coupling $g\sigma\cdot\nabla\tau\cdot\varphi$. Scattering and photoproduction equations are developed in an analogous manner to that discussed by Wick.[1] The specific S-wave interaction assumed in this work leads to scattering equations of the same form as that obtained from the dispersion relations.[2] An approximate solution to the scattering problem in the one meson approximation is in reasonable agreement with the experimental phase shifts up to 100 Mev. An exact relation is derived between the S-wave photoproduction from the dominant $\sigma\cdot A\tau\phi$ term and the scattering solution. As a result of the Kroll-Ruderman theorem, rescattering of the photoproduced S-wave meson alters the Chew-Low results by only five percent.

* This work has been supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] G. C. Wick, Revs. Modern Phys. **27**, 339 (1955).
[2] M. Goldberger (private communication).

DA3. Pion Nucleon Coupling Constant. G. F. CHEW AND U. HABER-SCHAIM, *University of Illinois.*—One of Goldberger's relations for the forward scattering of pions[1,2] is used in the following way. A linear function of ω^2, where ω is the total pion energy in the lab system is constructed from quantities taken from experiment, i.e., forward amplitudes and integrals over total cross sections. The extrapolation of this function to $\omega=0$ gives $2f^2$ where f is the renormalized pion nucleon coupling constant. The result of this relativistic

determination of the coupling constant will be compared with that derived from the static model.[3]

[1] Goldberger, Miyazawa, and Oehme, Phys. Rev. **99**, 986 (1955).
[2] Andersen, Davidon, and Kruse, Phys. Rev. **100**, 339 (1955).
[3] G. F. Chew and F. E. Low, Phys. Rev. **101**, 1570, 1579 (1956).

DA4. Pion Production in Pion-Nucleon Scattering. JERROLD FRANKLIN, *University of Illinois.*—The cross section for the production of one additional pion in a pion-nucleon collision has been calculated using the Chew-Low theory of P-wave pion-nucleon interaction.[1] The transition matrix element for the scattering of one meson into two is defined in terms of exact eigenstates of the total Hamiltonian, and an integral equation is obtained by expanding in a complete set of eigenstates. Limiting the sum over states to include only physical nucleon (no real mesons) states results in an expression for the one-to-two meson matrix element as a product of an elastic scattering matrix element and a meson emission matrix element. The experimental elastic scattering phase shifts were used in calculating the two meson cross section. The results of this calculation have been used to estimate the effect of the two meson states on the Low equation for the elastic scattering. The contribution to the "effective range" for elastic pion-nucleon scattering is small.

[1] G. F. Chew and F. E. Low, Phys. Rev. **101**, 1570, 1579 (1956).

DA5. General Theory of Multiple Boson Production.* YASUSHI TAKAHASHI, *State University of Iowa.*—We have derived a general formula for multiple boson production starting with the equation of motion for the boson $(\Box-\mu^2)U(x)=0(x)$. $0(x)$ may be any source function which satisfies the condition $[0(x), 0(y)]=0$ for $(x-y)^2>0$. The general formula immediately tells us the following facts: (1) When the boson energy is smaller compared with the mass of the source, the bosons can be radiated only from the external source lines of a total Feynman diagram, and give the logarithmic divergence at the low-energy limit. (2) Only the soft bosons are produced as a difference of the boson proper fields before and after the collision. Another expression of the general formula can be derived: Since the probability for n-boson production is symmetric with respect to the boson momenta, it is expressed in terms of the occupation number of bosons. The most probable distribution is obtained by variation of the occupation number subject to the energy conservation law. The formula written in this form shows a close relation between the discussions of field theory and of Fermi, which have been considered to be opposite extremes of each other.

* Supported by the National Science Foundation.

DA6. Results of the Lepore-Neuman Statistical Theory for Various Nuclear Events.* DAN H. HOLLAND, *University of California, Berkeley.*—The Lepore-Neuman statistical theory[1] has been used to calculate the relative probabilities for multiple pion creation and associated strange-particle production in nucleon-nucleon collisions at several energies, and the relative probabilities for the various modes of antinucleon annihilation. Final states consisting of two, three, and four particles are considered. The two-particle phase-space integrals can be done analytically, while the three- and four-particle cases require numerical integration. The energy distribution of pions created in nucleon-nucleon collisions is plotted, and lower energies than those predicted by the Fermi theory[2] are found to be favored. Multiplicities depend on the values chosen for the cut-off parameters, which play a role similar to the interaction volume in the Fermi theory. For antinucleon annihilation, the relative probabilities of final states consisting of 2π, $2K$, 3π, and 4π are $P_{2\pi}$: P_{2K}: $P_{3\pi}$: $P_{4\pi}$ equals 18.1:17.7:6.5:1, if all cut-off parameters are taken to be unity. These must be multiplied by the appropriate i-spin weight factors. Further modifications arise when selection rules imposed by invariance under charge conjugation and rotations in i-spin space are included.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] J. V. Lepore and M. Neuman, Phys. Rev. **98**, 1484 (1955).
[2] M. M. Block, Duke University (unpublished).

DA7. Neutron-Electron Interaction in Cut-Off Theory. S. B. TREIMAN AND R. G. SACHS, *Princeton University.*—The perturbation-theoretic result[1] for the neutron-electron interaction, as calculated in the Chew no-recoil approximation to pseudoscalar meson theory, is in serious contradiction with experiment. The experimental interaction (4.165 ± 0.265 kev) is largely accounted for by the Foldy term (4.08 kev). But the latter is not included in the no-recoil approximation, where one calculates only the electron interaction with the static pion charge cloud.[1] This term should contribute 0.085 ± 0.265 kev to the total interaction, whereas the perturbation result is $\sim$7.5 kev. Here we investigate the possibility that higher order mesonic corrections drastically alter the pion cloud charge distribution. Using the techniques described by Miyazawa,[2] one can express the higher order corrections in terms of weighted integrals over the pion scattering cross sections. It is found that the higher order effects indeed reduce the pion cloud contribution, but only by $\sim$20%. Because of certain ambiguities involved in treating the cut-off function, it cannot be stated that this represents the true content of Chew's theory, but it seems unlikely that any reasonable treatment could reduce the interaction much further.

[1] George Salzman, Phys. Rev. **99**, 973 (1955).
[2] H. Miyazawa (to be published).

DA8. Nucleon-Electron Interaction. RICHARD J. DRACHMAN AND GERALD FEINBERG,* *Columbia University.*—We have calculated the interaction of electrons with fixed nucleons in intermediate coupling, using a modified form of the pi-meson wave functions of Friedman, Lee, and Christian.[1] The results approximately substantiate Salzman's conclusions,[2] which are obtained by a perturbation method, concerning the low-energy neutron-electron potential. This depends only on r^2 averaged over the total charge distribution. For high-energy electron-proton scattering, which involves all moments of the distribution, we evaluate the charge density explicitly and compare it with the experimental results of Hofstadter.[3] Possible contributions of heavy mesons will be discussed.

* National Science Foundation predoctoral fellow.
[1] Friedman, Lee, and Christian, Phys. Rev. **100**, 1494 (1955).
[2] G. Salzman, Phys. Rev. **99**, 973 (1955).
[3] R. Hofstadter and E. E. Chambers, Bull. Am. Phys. Soc. Series II, 1, No. 1 (1956).

DA9. Dispersion Contribution to Electron-Deuteron Elastic Scattering.* H. S. VALK AND B. J. MALENKA, *Washington University.*—An attempt is made to estimate the contribution of the virtual intermediate states of the electron-deuteron system to high-energy elastic scattering. The contribution of these effects to the scattering amplitude is written in terms of the Born approximation expressed to second order in the Coulomb interaction. This term involves a sum over the complete set of a bilinear product of the deuteron wave functions and could be roughly treated by a previously suggested closure approximation.[1] However, since the proton-neutron system admits only one bound state which is the ground state of the deuteron, a more reasonable approximation should be obtained by keeping the deuteron ground state and replacing the continuum of excited states by the free particle wave functions for the proton-neutron system in the summation over intermediate states. To avoid orthogonality difficulties, a procedure relating the Green's functions of free and interacting nucleons is used. The results of this procedure will be reported.

* Supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] L. I. Schiff, Phys. Rev. **98**, 756 (1955).

DA10. Electron-Deuteron Scattering at High Energies. JEREMY BERNSTEIN, *Harvard University* (introduced by W. M. Preston).—We have employed the Born approximation to compute electron-deuteron scattering at high energies (200 Mev).[1] For small angles only one number is determined experimentally, the root-mean-square radius. This number is given to within a few percent by the triplet effective range as 1.96 Fermis. At large angles the Fourier transform of the deuteron wave function is needed to determine the angular distribution. Many wave functions have been tested; Hulthén, Gartenhaus, Blatt-Kalos, etc. The effect of D-state mixing has been found small. Magnetic effects as well as exchange current corrections were calculated.[2] Proton size effects have also been estimated. The possibility of using the experiments to learn of the existence of a repulsive core in the nuclear force will be discussed.

[1] McIntyre and Hofstadter, Phys. Rev. **98**, 158 (1955).
[2] J. Bernstein and A. Klein, Phys. Rev. **99**, 966 (1955).

DA11. A High-Energy Approximation for Relativistic Scattering Cross Sections.* L. R. B. ELTON,† *MIT* (introduced by H. Feshbach).—The short wavelength approximation of Molière[1] has been extended to take account of both relativistic and spin effects. The approximation is best at small angles, but still gives good agreement with exact calculations at 90°, even for large values of Z, both for Coulomb scattering and for scattering by an extended nucleus. The method should be particularly useful for calculating variations of the scattering cross section, when the form factor of the extended nucleus is varied. An extension to potentials not spherically symmetrical is discussed.

* This work was supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† On leave of absence from King's College London.
[1] G. Molière, Z. Naturforsch. **2A**, 133 (1947).

DA12. Momentum of Nucleons in Various Nuclei.* A. WATTENBERG, A. ODIAN, P. C. STEIN, AND R. WEINSTEIN, *MIT*.—In the photodisintegration of quasi-deuterons (neutron-proton pairs inside a nucleus), the kinematical relationships of a free deuteron are modified by the initial motion of the neutron-proton pair. We have employed this effect to study whether the "average" momentum of the nucleons is the same in Li, C, O, Al, and Cu. A simple theory employing only conservation of momentum was developed to interpret the data. It was found that a Fermi momentum distribution for the nucleons would not fit the data obtained from any of these nuclei. However, a Maxwellian distribution fits the data for Li, C, and O. The KT values are 8 Mev, 19 Mev, and 19 Mev, respectively. A one-parameter fit of the data indicates that Al and Cu may have a slightly higher "average" momentum than C and O. Less naive theoretical calculations have not improved the (perhaps fortuitously) good agreement of the experimental data with the simple theory.

* This work has been supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

THURSDAY AFTERNOON AT 2:00

Sheraton Park, Continental Room

(J. D. KURBATOV presiding)

Radioactive Nuclei, II

E1. Nuclear Levels in Tm^{169}.* E. N. HATCH, P. MARMIER, F. BOEHM, AND J. W. M. DUMOND, *California Institute of Technology*.—The K-capture decay of Yb^{169} into Tm^{169} has been studied using the curved crystal gamma spectrometer, the ring focusing beta spectrometer, and a semicircular low-energy beta spectrometer. The measured gamma-ray energies in kev and the assigned multipolarities of the transitions in Tm^{169} are the following: 8.42 ($M1$), 20.75 ($M1$), 63.12 $E1$, 93.60 $M1$, 109.78 $M1$, 118.20 $E2$, 130.53 $E2$, 177.24 $M1$, 197.97 $M1$, 240.4 ($E1$), 261.0 ($E1$), 307.7 $E2$. Following are the energies in kev of the assigned levels in Tm^{169}: A 8.42, B 118.20, C 138.95, D 316.19, E 379.31, F 472.91. Levels A, B, and C are interpreted as members of a rotational band which belongs to the $d3/2(K=\frac{1}{2})$ ground state, following the results of Mottelson and Nilsson.[1] Similarly, level D is interpreted as the $g7/2(K=7/2)$ particle excitation, and levels E and F as belonging to a rotational band from the $h11/2(K=7/2)$ particle excitation. From the energy values of states A, B, and C, we have calculated the rotational energy constant $\hbar^2/2\vartheta=11.969$ kev and the decoupling parameter $a=-0.7680$. A positive second-order correction term $\Delta E=+0.03389$ $[I(I+1)+a(-1)^{I+\frac{1}{2}}(I+\frac{1}{2})]^2$ kev was required. No other effects of admixtures of states outside the $K=\frac{1}{2}$ band were considered. The experimental $M1$ internal conversion coefficients in the K- and L-shells were observed to be about 15% to 25% below the theoretical values of Rose, in accord with data of Wapstra.[2]

* Work supported by the U. S. Atomic Energy Commission.
[1] B. R. Mottelson and S. G. Nilsson, Phys. Rev. **99**, 1615 (1955).
[2] A. H. Wapstra and G. J. Nijgh (to be published).

E2. Nuclear Levels in Lu^{175}.* F. BOEHM, E. N. HATCH, P. MARMIER, AND J. W. M. DUMOND, *California Institute of Technology*.—The energy levels excited in Lu^{175} by beta decay from Yb^{175} and by K-capture from Hf^{175} have been studied using the curved crystal gamma spectrometer and the ring focusing beta spectrometer. The energies in kev and the assigned multipolarities of the transitions in Lu^{175} following beta decay of Yb^{175} are: 113.81 85% $M1+15\%$ $E2$, 137.65 $M1+E2$, 144.85 $E1$, 251.3 ($E2$), 282.57 $E1+M2$, 396.1 $E1+M2$. The energies in kev and the multipolarities of the transitions in Lu^{175} following K-capture of Hf^{175} are: 61.69, 89.36 98% $M1+2\%$ $E2$, 113.81 85% $M1+15\%$ $E2$, 161.3, 229.57 $E2$, 318.9 $M1$, 343.46 $M1$, 432.8 $M1$. The observed K and L_I internal conversion coefficients for the 89.36-kev transition are more than 30% lower than the theoretical values by Rose. Following are the energies in kev of the levels in Lu^{175}. A 113.81, B 251.46, C 343.40, D 396.31, E 432.76. Levels A and B being rotational levels belonging to the $g7/2(K=7/2)$ ground state, the rotational energy constant $\hbar^2/2\vartheta=12.913$ kev was computed neglecting the effect of admixtures of other states. A vibration-rotation correction term $E=-0.00659$ $I^2(I+1)^2$ kev was required. The interpretation of levels C and E as belonging to the $d5/2(K=5/2)$ rotational band and of level D as the $h11/2(K=9/2)$ particle excitation is in agreement with that of Wilets and Chase. Transition probabilities between the levels will be discussed.

* Work supported by the U. S. Atomic Energy Commission.

E3. Radiations from Au^{195}.* V. R. POTNIS,† *Bartol Research Foundation*.—The radiations from Au^{195} have been examined

previously in magnetic spectrometers and coincident Geiger counter arrangements. Two gamma rays with energies about 31 and 99 kev were found to be in cascade in all these studies. The data concerning the presence of the 130-kev crossover transition of the 31- to 99-kev cascade have been inconclusive. In order to find some definite evidence of the presence of the 130-kev gamma ray, the radiations from Au^{195} were examined with the scintillation spectrometer of NaI(Tl). The presence of 31-, 99-, and 130-kev gamma rays is seen in the pulse-height distribution of the gamma rays. Absorption experiments on each gamma ray were carried out. It has been shown that the 130-kev gamma ray is not due to the simultaneous detection of the two lower energy gamma rays in cascade. Coincidence data will be presented, and the decay scheme for Pt^{195} will be discussed.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Permanent address, Gwalior (M.B.) India.

E4. Search for Radioactive Pt^{200}.* G. W. Warren and R. W. Fink, *University of Arkansas.*—A search for Pt^{200} was made by irradiating 400 mg of "specpure" platinum metal in the LITR for 32 days. Failure to detect long-lived activity ($\geq$3.8 days) in the chemically purified platinum fraction sets a limit, $\sigma\lambda \leq 425$ barns/hour, where σ is the cross section for $Pt^{199}(n,\gamma)Pt^{200}$ and λ is the decay constant of Pt^{200}, assuming a flux of 8.6×10^{12} neutrons/cm²-sec. After initial purification to remove Au^{199}, subsequent fast gold separations at a time 48 hours after the end of irradiation failed to reveal 48-min Au^{200} daughter activity. An 82-day activity reported previously[1] was shown chemically and by scintillation spectrometry to be 76-day Ir^{192}, produced by activation of subspectroscopic amounts of iridium impurities.

* Taken from the M.S. thesis of G. W. Warren; supported in part by the U. S. Atomic Energy Commission and the National Science Foundation.
[1] Cork, Stoddard, Rutledge, Branyan, and LeBlanc, Phys. Rev. **77**, 843 (1950).

E5. Search for Radioactive Hg^{206}.* R. W. Fink, G. W. Warren, B. L. Robinson, and R. R. Edwards, *University of Arkansas.*—A search was made for Hg^{206} by irradiating Hg^{204}, enriched to 89%, for 5 weeks in the MTR at a rms flux of 2×10^{14} neutrons/cm²-sec. Failure to detect activity (>10 hours or <2 years) other than 45-day Hg^{203} in the chemically purified mercury fraction gives a limit, $\sigma\lambda \leq 330$ barns/hour, where σ is the cross section for $Hg^{205}(n,\gamma)Hg^{206}$ and λ is the decay constant of Hg^{206}. A possible daughter, 4-min Tl^{206}, was shown to be absent. No activity was found in the mercury, gold, and platinum fractions isolated chromatographically[1] from 3 millicuries of RaDEF (spent radon seeds) at least 4 years old. Assuming 1 day $< T_{\frac{1}{2}} <$ 2 years for Hg^{206}, this sets an upper limit for alpha decay of Pb^{210} of $(6\pm1)\times10^{-6}$ α's/dis. By separating 4-min Tl^{206} with known chemical yield from 3 millicuries of equilibrium RaDEF, the alpha-branching ratio of RaE is $(1.7\pm0.2)\times10^{-6}$ per disintegration, which compares with the rough limits $(2$ to $70)\times10^{-6}$ set by Broda and Feather.[2] No long-lived Tl^{206} was found in either the MTR irradiation or the RaDEF studies.

* Taken in part from the M.S. thesis of G. W. Warren; supported in part by the U. S. Atomic Energy Commission and the National Science Foundation.
[1] G. W. Warren and R. W. Fink, J. Inorg. Nuclear Chem. **2** (to be published).
[2] E. Broda and N. Feather, Proc. Roy. Soc. (London) **A190**, 20 (1947).

E6. Radioactive Decay of Th^{231}.* J. P. Mize and J. W. Starner, *Los Alamos Scientific Laboratory.*—The radiations of Th^{231} (25.6 hr) have been studied with a 141-gauss, 180° permanent magnet spectrograph, scintillation coincidence spectrometers, and an aluminum-lined proportional counter spectrometer. Nuclear levels in Pa^{231} excited by the Th^{231} disintegration occur at 249.2, 190.7, 109.6, and 25.5 kev. The levels are connected by a quadruple cascade of gamma transitions whose energies and multipolarities were experimentally determined as 58.5 kev ($E2$), 81.1 kev ($M1+E2$), 84.4 kev ($M1+E2$), and 25.5 kev ($E1$). With the exception of the 25.5-kev transition, whose multipolarity was deduced from intensity considerations, multipolarity assignments were based on L-subshell conversion electron studies. Stopover gamma transitions between the levels at 249.2—25.5, 249.2—109.6, and 190.7—25.5 kev were observed with the scintillation apparatus. The most energetic beta group of Th^{231} was found to be 305 ± 10 kev, and through beta-gamma coincidence studies this group was observed to terminate at the 109.6-kev level of Pa^{231}. Spin and parity assignments for the nuclear levels in Pa^{231} based on experimental evidence and nuclear model considerations will be presented.

* Work done under the auspices of the U. S. Atomic Energy Commission.

E7. Radiations of Np^{234}.* J. R. Huizenga, D. W. Engelkemeir, M. S. Freedman, F. T. Porter, and J. E. Gindler, *Argonne National Laboratory.*—The radiations of Np^{234} have been studied with a magnetic lens beta-ray spectrometer and gamma-scintillation spectrometers. The Np^{234} was made by bombarding U^{235} with deuterons. The conversion electron lines observed in the lens spectrometer are interpreted as owing to transitions of 43, 109, 234, 247, 449, 517(?), 752, 813, and 1567 kev. We observed no conversion electrons which could be interpreted as a 1420-kev transition.[1] The following gamma rays were observed with a NaI spectrometer: 445, 500, 720, 905, 1010, 1190, and 1540 kev. Coincidence measurements with the scintillation spectrometers showed all the latter gamma rays to be in coincidence with uranium K x-rays. In addition coincidences were observed between the following gamma rays; 500 with the 445, 720, 905, and 1010, 720 with the 445 and a gamma of approximately 750 kev, 1190 possibly with a 235, and the 1540 with excess L x-rays (probably owing to coincidence with the 43-kev transition). The levels in U^{234} populated by the electron capture of Np^{234} will be compared with the levels observed in the beta decay of Pa^{234}.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.
[1] D. A. Orth, thesis, UCRL-1059 (1952).

E8. Intensities of X-Rays and γ Rays in Am^{241} α Decay.* L. B. Magnusson and D. W. Engelkemeir, *Argonne National Laboratory.*—To avoid the uncertainty in counting efficiency near the edges and surfaces of NaI scintillation crystals, we have determined absolute intensities of the low-energy radiations in beams collimated to enter only the central portion of the crystal face. A ¼-in. diam sample, 2.8×10^5 α d/m, was deposited by vacuum evaporation on 1-mil Al foil. Six measurements with different collimators (transmission factors of *ca* 0.026 and 0.012) and two types of detecting crystals gave an average intensity of 0.330 ± 0.001 per alpha particle for the full-energy 59.6-kev peak. The escape peak intensity from five measurements was 10.9% of the total pulses, somewhat lower than a calculated value.[1] Corrected photon intensities per alpha particle are 0.37 ± 0.02, 0.027 ± 0.007, and 0.370 ± 0.004 for total L x-rays, 26.4-kev gamma, and 59.6-kev gamma, respectively.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Peter Axel, Brookhaven National Laboratory Rept. No. BNL 271 (September, 1953).

E9. Gamma-Gamma Angular Correlation in Au^{197}. J. V. Kane and S. Frankel, *The University of Pennsylvania.*—The angular correlation of the 130- to 279-kev gamma-gamma cascade in Au^{197} has been measured with a fast coincidence NaI scintillation spectrometer. The experimental anisotropy was -0.283 ± 0.012. Correcting for the finite source size and detector solid angle for an $11/2(E3)\ 5/2(M1+E2)3/2$ cascade, this anisotropy implies a correlation function $W(\theta)=1-(0.299$

$\pm 0.012)P_2(\cos\theta)$ with a negligible P_4 contribution. The foregoing correlation gives $\delta^2 = 0.12 \pm 0.03$ or 2.0 ± 0.3. The sign of δ is negative in agreement with the Coulomb excitation angular distribution measurements of several authors.[1-3] The smaller value of δ^2 agrees with values of δ^2 computed using the measured α_k and the theoretical α_k's of Sliv. It also agrees with the measured K/L ratios and the K/L ratios of Rose, but not with the K/L ratio obtained using Sliv's K-conversion coefficients and Rose's L-conversion coefficients. Details of these comparisons will be discussed.

[1] W. I. Goldburg and R. M. Williamson, Phys. Rev. 95, 767 (1954).
[2] Cook, Class, and Eisinger, Phys. Rev. 96, 658 (1954).
[3] F. K. McGowan and P. H. Stelson, Phys. Rev. 99, 127 (1955).

E10. Determination of Relative Fermi and Gamow-Teller Contributions to Allowed Beta Decay (Co^{56}) by Nuclear Orientation.* P. S. JASTRAM, C. M. SCHROEDER, AND R. C. SAPP,† *The Ohio State University.*—The results of measurements of the angular distribution of the 0.845-Mev gamma ray following positron decay of Co^{56} nuclei oriented at low temperatures have been combined with the recently determined spin and magnetic moment[1] of the Co^{56} ground state to yield information on the relative contribution of Fermi and Gamow-Teller interactions to the Co^{56} positron decay. The linear Fermi plot and occurence of appreciable electron capture indicate that the 1.5-Mev positron is allowed; the temperature dependence of the gamma-ray anisotropy is found to be compatible with this assignment, but only provided the transition probability contains appreciable contributions from both Fermi and Gamow-Teller interactions. The best fit with present data occurs for approximately equal proportions. Anisotropy measurements are continuing at different external orienting field strengths to test whether the experimental ratio of the Fermi and G. T. contributions remains appropriately independent of the orientation mechanism, and, if possible, to improve the precision with which the ratio is determined.

* Supported by the National Science Foundation.
† Welsh Foundation postdoctoral fellow. Present address: The Rice Institute, Houston, Texas.
[1] Jones, Dombrowski, and Jeffries (private communication).

E11. Continuous Gamma Rays of Tl^{204}, Co^{57}, Sn^{113}, and Mn^{54}. R. G. JUNG* AND M. L. POOL, *The Ohio State University.*—Continuous gamma rays associated with electron capture transitions were measured by a coincidence technique. The single channels consisted of $1\frac{1}{2}$ by 1 cylindrical NaI crystal, photomultiplier, cathode follower, amplifier, and single-channel analyzer. The resolving time of the coincidence circuit was 0.085 μsec. Coincidences between the Hg K x-rays and the continuous gammas were observed in the electron capture disintegration of Tl^{204}. The Fermi plot of the distribution, corrected for change in crystal efficiency, showed an end point of 0.293 ± 0.020 Mev. Adding to this, the Hg K-electron binding energy, a transition energy of 0.376 ± 0.020 Mev was obtained. The log ft value is 9.33 indicating a $\Delta I = 2$, yes, transition. Coincidences between the continuous gammas and the monoergic gammas of Co^{57} showed a transition energy of 0.434 ± 0.030 Mev. The log ft value is 5.84 corresponding to a $\Delta I = 0$, no, transition. Coincidences between the K x-rays and the continuous gammas of Sn^{113} gave a transition energy of 0.100 ± 0.10 Mev. The log ft value is 4.65 corresponding to an allowed transition. Coincidences between Cr K x-rays and the continuous gammas of Mn^{54} gave a transition energy of 0.528 ± 0.020 Mev. The log ft value is 6.15.

* Now with the Battelle Memorial Institute, Columbus, Ohio.

THURSDAY AFTERNOON AT 2:00

Shoreham, Main Ballroom

(R. H. HILDEBRAND presiding)

Mesons

EA1. Interactions of 6.2-Bev Protons. G. ASCOLI AND U. HABER-SCHAIM, *University of Illinois.*—The 6.2-Bev proton tracks were followed through an emulsion stack. Results on elastic and inelastic scattering cross sections will be presented. Some indications as to the energy spectrum of the pions will be mentioned.

EA2. Energy Spectrum of Pions from 2.2-Bev Protons on Be.* F. L. NIEMANN, J. K. BOWKER, W. M. PRESTON, AND J. C. STREET, *Harvard University.*—Nuclear emulsions have been exposed to the radiation from an internal Be target bombarded by 2.2-Bev protons in the east straight section of the Brookhaven Cosmotron. The identity and energy of the particles were determined by scattering measurements and grain count. Approximately 500 tracks, of which 200 proved to be pi mesons, have been analyzed in plates at laboratory angles of 18° and 36° from the incident beam. Work continues on tracks at 12°. The energy distributions for the pions have been obtained in the center-of-mass system assuming a simple nucleon-nucleon interaction in the target. Within the limits of the statistics the data for the pions at 36° (lab) agrees with that previously obtained at 32°.[1] The energy spectra of the pions at 18° and 36°, corresponding to particles near 45° and 90° in the c.m. system, both exhibit a marked maximum at about 100 Mev. There is also evidence that the integrated intensity is significantly greater at the forward angle. In the energy range 150 to 300 Mev (c.m.) this asymmetry is considerably more evident.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Luke, Yuan, and Lindenbaum, Phys. Rev. 93, 1431 (L) 1954.

EA3. Multiple Meson Production.* D. LUCKEY AND R. R. WILSON, *Cornell University.*—The reaction $\gamma + p \rightarrow \pi^- + \pi^+ + p$ is being investigated using the x-ray beam of the new Cornell strong-focusing synchrotron which gives energies up to one Bev at present. Negative mesons are measured in the above reaction by means of the same double-focusing magnet which was employed in the study of photoproduction in the range 200–300 Mev.[1] By the use of four scintillation detectors, the background, owing to neutron induced counts, has been reduced to zero. Preliminary measurements at 45° using a synchrotron energy of 800 Mev and detecting 65-Mev mesons have been made using a $CH_2 - C$ subtraction method. The absolute photoproduction for π^- in C is $0.4 \mu b$ sterad^{-1} Mev^{-1} Q^{-1} and the π^-/π^+ ratio for C is 1.17 ± 0.14. This is so large that it masks the negative meson production in H. A liquid hydrogen target has been constructed, and measurements of the production rate in H at different angles and energies are proceeding apace.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Jenkins, Luckey, Palfrey, and Wilson, Phys. Rev. 95, 179 (1954).

EA4. Multiple Meson Production. D. T. KING, *The University of Tennessee.*—Cosmic-ray "jet" stars, with (a) no black or gray tracks and (b) a number of shower particles $n_s \geqslant 6$, have been examined. Of those showing a charge balance consistent with a proton target, five have a singly charged primary and three have a neutral primary. The energies of the incident particles lie in the interval 10 to 500 Bev and are determined from the polar angles of the outgoing particles by the method of Castagnoli *et al.*,[1] which assumes a free nucleon-nucleon collision. An attempt is made to derive the angular distributions of the created mesons in the center-of-mass systems of the colliding particles. A comparison of the numbers and emission angles of the outgoing mesons indicates that only about 20% of such "jets" are attributable to hydrogen collisions.

[1] Castagnoli, Cortini, Franzinetti, Manfredini, and Moreno, Nuovo cimento **10**, 1539 (1953).

EA5. Photoproduction of π^+ Mesons from Hydrogen and Deuterium near Threshold.* S. PENNER† AND C. S. ROBINSON, *University of Illinois.*—An earlier experiment[1] to measure π^+ photoproduction from hydrogen has been repeated, and the photoproduction from deuterium measured with the same apparatus. Mesons from hydrogen or deuterium stop in a carbon absorber surrounding the target, and the resulting positrons are counted in a scintillator telescope. The activation curves obtained have been analyzed for cross sections from threshold to 180 Mev. The total cross sections obtained will be given. The effect of the shape of the μ-decay spectrum on the absolute values will be discussed. The deuterium/hydrogen cross-section ratio is found to be 0.3 at threshold and 0.75 at a center-of-mass meson momentum of 80 Mev/c. The ratios obtained will be compared with theory.[1]

* Supported in part by the Office of Naval Research, U. S. Atomic Energy Commission, and National Science Foundation.
† General Electric fellow.
[1] Leiss, Robinson, and Penner, Phys. Rev. **98**, 201 (1955).

EA6. π^0-Meson Photoproduction in Complex Nuclei at Forward Angles.* R. MEUNIER,† L. S. OSBORNE, AND R. L. BARRINGER, *MIT.*—The angular differential cross sections for photoproduction of 250 Mev π^0 mesons in several elements from 0° to 90° were measured with the equipment described in the previous abstract. Targets used were Li, Be, C, Al, Cu, Pb. Production per nucleus near 0° is consistent with an $A^{4/3}$ dependence. Between 0° and 40° each element shows a well-defined maximum. This maximum appears at smaller angles for heavier elements. Thereafter, up to 90°, the cross section decreases, with a secondary maximum for copper. The finite resolution of our counter ($\approx 15°$ at 0°) was such that our data do not rule out a negligible cross section at 0° with respect to the gamma-ray beam. This is consistent with coherent photoproduction from complex nuclei with a $\sin^2\theta$ dependence, and strong nuclear π^0 absorption, of the order of the known π^+ nuclear absorption.[1] Theoretical fits will be shown.

* This work was supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† National Council Fellow under a Foreign Operation Administration grant.
[1] R. M. Littauer and D. Walker, and Phys. Rev. **86**, 838 (1952); Handler, Osborne, and Richter, MIT Laboratory for Nuclear Science, Progress Rept., August 31, 1955, p. 57. H. A. Bethe and R. R. Wilson, Phys. Rev. **83**, 690 (1951).

EA7. π^0-Meson Photoproduction from Hydrogen and Deuterium.* R. L. BARRINGER, L. S. OSBORNE, AND R. MEUNIER,† *MIT.*—We measured the angular differential cross section for photoproduction of π^0 mesons in liquid hydrogen and deuterium from 0° to 180° for a gamma-ray incident energy of 250 Mev. The gamma rays were produced in the Massachusetts Institute of Technology 320-Mev synchrotron. The two meson-decay gamma rays were detected in coincidence (resolving time $\approx 10 \times 10^{-9}$ sec) with gamma-ray telescopes in a yoke arrangement. Each telescope consisted of two scintillation counters and a Čerenkov counter. The cross section for hydrogen can be represented by $\sigma = A \times [(1.0 \pm 0.1) - (0.66 \pm 0.045)\cos\theta - (0.53 \pm 0.11)\cos^2\theta]$ (arbitrary units) in agreement with previous measurements.[1] The yield of mesons at energies corresponding to elastic production from deuterium compared to hydrogen is (meson yield per nucleus):

	0°	30°	60°	90°	180°
$\frac{\text{deuterium}}{\text{hydrogen}}$	1.6	2.5	2.1	1.7	0.8

* This work was supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† National Council Fellow under a Foreign Operation Administration Grant.
[1] Goldschmidt-Clermont, Osborne, and Scott, Phys. Rev. **97**, 188 (1954). D. C. Oakley and R. L. Walker, Phys. Rev. **97**, 1283 (1954).

EA8. π^+-Photomeson Production as a Function of Atomic Number.* W. IMHOF, E. KNAPP, AND V. PEREZ-MENDEZ, *University of California, Berkeley and Livermore.*—The yield of π^+ mesons from H, C, Al, Cu, Ag, and Pb produced by the bremsstrahlung beam of the Berkeley 335-Mev synchrotron has been measured at 135° to the beam line. With a detection scheme improved over that previously reported,[1] the production of lower energy pions has been studied more extensively. A magnetic field and an anticoincidence circuit have been added as further aids in reducing the electron background. Data will be presented on the relative yield of pions of mean energies 12, 16, 22, 30, 36, 46, and 65 Mev each with a total energy spread of 8 to 10 Mev. The results will be interpreted in terms of the mean free path for interaction of mesons in nuclear matter and effects of the nuclear Coulomb barrier.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] Imhof, Perez-Mendez, and Easterday, Phys. Rev. **100**, 1798(A) (1955).

EA9. Photoproduction of Pion Pairs at 500 Mev. VINCENT Z. PETERSON, *California Institute of Technology.*—The existence of low-energy negative pions from hydrogen irradiated with 500-Mev bremmstrahlung, reported earlier,[1] has been confirmed by additional experiments. Emulsion detection permits recording mesons of very low energy (13 Mev) and provides clear-cut identification of pions of both charges. The background of stopped pions is due mainly to cosmic-ray tracks which can be rejected on basis of direction. The results at 140° (lab) show a steep energy dependence in the π^-/π^+ ratio, decreasing from $26 \pm 8\%$ to $0 \pm 2\%$ as the pion energy increases from 20 to 65 Mev (pion pair limit is 59 Mev). The ratio at 73° is $16 \pm 6\%$ at 25 Mev and $4 \pm 2\%$ at 54 Mev. This sensitivity to meson energy may partially explain the low yield at 47 Mev found by Sands *et al.*[2] Both Cutkovsky and Zachariasen (private communication) have related pion pair production to pion-nucleon scattering and predict, for energies not too far from threshold, a strong preference for the π^- to be emitted in an S-state. The present results, as well as those of Crowe[3] at 575 Mev, are consistent with this prediction.

[1] V. Z. Peterson and I. G. Henry, Phys. Rev. **96**, 850 (1954).
[2] Sands, Bloch, Teasdale, and Walker, Phys. Rev. **99**, 652 (1955).
[3] Friedman and Crowe, Phys. Rev. **100**, 1799 (A) (1955).

EA10. Total Pion-Proton Cross Section above 0.9 Bev.* R. L. COOL AND O. PICCIONI,† *Brookhaven National Laboratory.*—New measurements have been made of the positive and negative pion-proton total cross sections in the energy range from 0.9- to 1.8-Bev kinetic energy. Making use of the ejection system for the external proton beam of the cosmotron, positive as well as negative pions have been obtained up to the highest energy. A liquid-hydrogen absorber was used exclusively. A detailed study of the total cross section above 1 Bev showed a new maximum for $\sigma(\pi^+,p)$ that was only suggested by, but not outside the uncertainty of, the previous measurement of the $D_2O - H_2O$ difference using negative pions. While $\sigma(\pi^-,p)$ is

nearly constant at 30 mb in this energy region, $\sigma(\pi^+,p)$ crosses the $\sigma(\pi^-,p)$ curve at 1.15 Bev, rises to a maximum of 39 mb near 1.35 Bev, and then falls again to 30 mb above 1.55 Bev. The assistance of J. W. Cronin, A. Abashian, and C. F. Woolley, Jr., in making these measurements is gratefully acknowledged.

* Under contract with the U. S. Atomic Energy Commission.
† Now on leave at Radiation Laboratory, University of California.

EA11. 720 Mev π^--p Scattering. M. L. Good, Hugh Bradner, F. S. Crawford, and M. L. Stevenson, *University of California, Berkeley.*—Interactions of negative π mesons from the Bevatron have been observed in the 4-in. liquid hydrogen bubble chamber. Of 55 events analyzed, 34 are elastic scatters. Seven others are nearly coplanar, but do not have angles appropriate to elastic scatter. The following angular distribution of elastic π scatters in equal increments of $\cos\theta$ was found:

$\cos\theta_\pi$ (cm)	No events
1.0 to 0.6*	18
0.6 to 0.2	11
0.2 to −0.2	2
−0.2 to −0.6	2
−0.6 to −1.0	3

The strong forward peak is consistent with diffraction scattering, of cross section comparable with inelastic cross section. Twenty-one inelastic events, consisting of $\pi^-+\pi^++n$, and $\pi^-+\pi^0+p$ were found. One case of $3\pi^\pm+p$ was seen.

* Corrected for scanning cutoff at approximately 15°.

EA12. π^+-p Interactions at 470 Mev.* M. E. Blevins, M. M. Block, and E. M. Harth, *Duke University.*—A previous study of 500-Mev π^+-p interactions[1] in a large hydrogen diffusion chamber has been continued with a magnet diffusion chamber.[2] The chamber was located in a magnetic field of 9000 gauss, and exposed to a 500-Mev external π^+ beam from the Brookhaven Cosmotron. In 6000 pictures, 49 interactions were found. About 10% of the total cross section is determined to be inelastic. The kinetic energy of the incident pion beam was 470±80 Mev as found by momentum analysis. The center-of-mass angular distribution of the outgoing pions in the elastic events seems to show a pronounced forward peaking. This work is preliminary to a study of 33 000 pictures taken with the magnet chamber at the Brookhaven Cosmotron.†

* Work supported jointly by the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Blevins, Block, and Harth, Phys. Rev. **99**, 1628 (1955).
[2] Fowler, Fowler, Shutt, Thorndike, and Whittemore, Phys. Rev. **91**, 135 (1953).
† The cooperation of Dr. R. P. Shutt and the Brookhaven Cloud Chamber Group in exposing this film is greatly appreciated.

EA13. Pion-Proton Elastic Scattering Cross Sections at 42 Mev and 38°.* S. W. Barnes, B. Rose, G. Giacomelli, and L. Velinsky, *University of Rochester.*—Measurements of the differential $\pi-p$ scattering cross sections of 42±3 Mev pions at a laboratory scattering angle of 38°±7½° have been continued. New data, together with a reevaluation of previous data, give at present the center-of-mass values of 0.36±0.004 and 0.61±0.08 mb/sterad for π^+ and π^-, respectively.

* Supported by the U. S. Atomic Energy Commission.

EA14. $\mu^+-\beta^+$ Decay Spectrum.* Ryokichi Sagane,† Walter F. Dudziak, and James Vedder. *University of California, Berkeley.*—In the last three years disagreements among experiments created some confusion as to the shape of the positron spectrum from the decay of the muon. Measurements of the spectrum by conventional methods[1] yielded results that were best described by ρ (the Michel parameter) ~0.6. Measurements made with a new type of spiral-orbit spectrometer[2] that permits large solid-angle focusing gave $\rho\sim0.23$. From a careful experimental study—using (a) scattered electrons and (b) monoenergetic alpha particles—of spiral-orbit spectrometer properties of different magnetic geometries, we found a systematic error in our published preliminary results. The error increased with positron energy (from 40 to 53 Mev) and was caused by a partial saturation of two magnetic pole tips in the region where the radial magnetic field variation was greatest. Since ρ is mainly determined by measurements made at positron energies greater than 40 Mev, correction makes a drastic change in our reported ρ value. The corrected old results, as well as new spiral-orbit measurements, will be described. These yield a value of $\rho=0.62\pm8\%$, removing the discrepancy.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
† Now in Tokyo, Japan.
[1] J. Vilain and R. Williams, Phys. Rev. **94**, 1011 (1954); K. Crowe *et al.*, Phys. Rev. **99**, 872 (1955); C. Sargent *et al.*, Phys. Rev. **99**, 885 (1955).
[2] Sagane *et al.*, Phys. Rev. **95**, 863 (1954).

EA15. Lifetimes of Negative Muons in Various Materials.* M. Weinrich and L. M. Lederman, *Columbia University.*—The Z-dependence of the capture rate of negative muons is being studied at the Nevis Cyclotron. Following a suggestion of Steinberger, the relative rates are observed simply by counting the absolute number of electrons emerging from a target per stopping muon. Target materials are calibrated for stopping power and electron interactions in the positive muon beam. A preliminary run gave the following results (all relative to carbon):

$\tau(\mathrm{Be})/\tau(\mathrm{C})=1.12\ \pm0.06$;	$\tau(\mathrm{Al})/\tau(\mathrm{C})=0.42\ \pm0.03$;
$\tau(\mathrm{Ti})/\tau(\mathrm{C})=0.15\ \pm0.02$;	$\tau(\mathrm{Fe})/\tau(\mathrm{C})=0.10\ \pm0.01$;
$\tau(\mathrm{Cu})/\tau(\mathrm{C})=0.082\pm0.006$;	$\tau(\mathrm{Mo})/\tau(\mathrm{C})=0.054\pm0.004$;
$\tau(\mathrm{Cd})/\tau(\mathrm{C})=0.050\pm0.005$;	$\tau(\mathrm{Bi})/\tau(\mathrm{C})=0.038\pm0.006$.

Statistics will be improved and results compared to the theory of Primakoff.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

Thursday Afternoon at 2:00

Shoreham, West Ballroom

(J. A. Harvey presiding)

Neutrons, I

F1. Small-Angle Elastic Scattering of 5-Mev Neutrons from Carbon, Aluminum, Iron, Copper, and Lead.* R. W. Hill, *Westinghouse Research Laboratories.*—The differential cross sections for elastic scattering of 5-Mev neutrons by carbon, aluminum, iron, copper, and lead were measured at five-degree intervals between 10° and 35° by the ring geometry technique. A biased scintillation detector consisting of twelve ½ in. diameter by ½ in. long cylinders of plastic scintillator was used to count the scattered neutrons. Theoretical cross sections calculated using the complex square-well potential of Feshback,

Porter, and Weiskopf[1] are in good agreement with the experimental results.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Feshbach, Porter, and Weisskopf, Phys. Rev. 96, 448 (1954).

F2. Scattering of 4.3-Mev Neutrons by Al, Cr, Co, Ni, Pb, and Bi.* R. V. SMITH, *Westinghouse Research Laboratories.*—Neutron spectra resulting from the scattering of 4.3-Mev incident neutrons have been measured at 90° by a time-of-flight technique,[1] for aluminum, chromium, cobalt, nickel, lead, and bismuth. The method resolves groups corresponding to elastic scattering, inelastic scattering in the region 1–3 Mev excitation, and the de-excitation gamma rays. In general, the results confirm the known levels of these elements.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] R. V. Smith, Bull. Am. Phys. Soc. Series II, 1, No. 1, 55 (1956).

F3. Scattering of Neutrons from F^{19} and C^{12} between 0.5 and 5 Mev. JAMES E. WILLS, JR.,* *Oak Ridge National Laboratory.*—Neutron total cross-section measurements for fluorine were made between 0.5 Mev and 5 Mev. Angular distributions of neutrons scattered from carbon and fluorine were obtained at 0.66, 1.05, 1.45, and 2.15 Mev. Although interference from nearby resonances were undoubtedly present in fluorine, attempts were made to determine the potential scattering phase shifts from the distributions. The analysis indicates that the s-wave phase shift is larger than that calculated for a hard sphere of reasonable radius. In fluorine, the p-wave phase shift is about the same as that computed for a hard sphere. The d-wave shift is somewhat smaller. In carbon, both the p- and d-wave shifts were smaller than those calculated for a hard sphere. The 2.15-Mev distribution for carbon showed a small amount of interference from a resonance at 2.07 Mev. Careful measurements of the total cross section of carbon in the vicinity of 2.07 Mev with a resolution of 1.7 kev indicates that the resonance has a spin of $\frac{3}{2}$ and a width of 11 kev. Measurement of the asymmetries of the angular distributions in the vicinity of the resonance indicates that it is owing to d-waves.

* Oak Ridge Institute of Nuclear Studies Graduate Fellow from the University of Texas.

F4. Inelastic Scattering of 14-Mev Neutrons from C^{12}.* JACK BENVENISTE, CALVIN C. GARDNER, M. PAUL NAKADA, AND CALVIN WONG, *University of California, Livermore.*—Bursts of 14-Mev neutrons produced by sweeping and bunching the beam of the 500-kev Cockcroft-Walton accelerator were scattered from C^{12} in ring geometry and detected in a *trans*-stilbene crystal. The energy distribution of the scattered neutrons was measured by the time-of-flight technique. Data will be presented on observations of the states of C^{12} at several angles.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

F5. Energy Dependence of the Efficiency of a Stilbene Neutron Detector.* CALVIN WONG, JACK BENVENISTE, CALVIN C. GARDNER, AND M. PAUL NAKADA, *University of California, Livermore.*—In measuring cross sections of inelastically scattered neutrons, it is necessary to know the detector efficiency as a function of neutron energy. With 14-Mev neutrons incident, observations of neutrons scattered from rings of C and CH_2 at various angles give detector efficiencies relative to known n-p cross sections. Measurements show that the carbon in the scintillator contributes appreciably to the efficiency above about 10 Mev. The arrangement used in measuring inelastic spectra and detector efficiencies will be described. Effects owing to shielding around the detector and material in the vicinity of the target will be discussed.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

F6. Differential Elastic Scattering of Neutrons from Neon. H. O. COHN AND J. L. FOWLER, *Oak Ridge National Laboratory.*—A new method has been developed for determining the differential elastic scattering cross section of neutrons from nuclei in a gaseous form. Coincidences are taken between nuclear recoil pulses in a proportional counter filled with the gas and the pulses due to the scattered neutrons detected by an anthracene crystal. The direct source neutrons are shielded from the region of the anthracene crystal by LiF impregnated paraffin. Real coincidences, caused by the γ-ray background, and accidental coincidences must be evaluated and subtracted. The method was used to investigate some of the resonances in neon.[1] The neutron source was the $T(p,n)$ reaction produced by protons from the Oak Ridge National Laboratory Van de Graaff machines. Differential scattering at $\cos\theta(\text{c.m.}) = \pm 0.58$ was found to be symmetrical about $\cos\theta = 0$ for the 1.68 Mev level,[1] whereas for the 1.62 Mev level the cross section was found peaked toward forward neutron scattering. If the potential scattering is predominantly s-wave, and off-resonance data suggest this to be the case, then the results indicate the 1.62-Mev level has odd parity and the 1.68-Mev level has even parity.

[1] H. O. Cohn and J. L. Fowler, Phys. Rev. 99, 1625 (1955).

F7. Nonelastic and Elastic Scattering Cross Sections of High-Energy Neutrons.* T. W. BONNER AND J. H. SLATTERY, *The Rice Institute.*—Previous experiments[1] have indicated a marked difference between the variation of neutron cross sections as a function of energy for elastic and nonelastic scattering. Experiments using the same techniques have been carried out which extend the cross-section measurements to neutron energies of 8.2 Mev and 9.8 Mev in Cu, Ag, Sn, Pb, and Bi. The results confirm the previous indication that the nonelastic cross sections vary slowly as the neutron energy is increased from 5 to 15 Mev, while the elastic cross sections show marked maxima and minima. At a neutron energy of 10 Mev the nonelastic cross sections in Pb and Bi (2.58b and 2.52b) are larger than the elastic cross sections (2.02b and 2.23b).

* Supported in part by the U. S. Atomic Energy Commission.
[1] Taylor, Lönsjö, and Bonner, Phys. Rev. 100, 174 (1955).

F8. Interactions of 2.45-Mev Neutrons.* JULES S. LEVIN AND LAWRENCE CRANBERG, *Los Alamos Scientific Laboratory.*—A time-of-flight apparatus in conjunction with a pulsed beam from the large Los Alamos electrostatic accelerator has been used to study the interaction of 2.45-Mev neutrons with a variety of elements.[1] When these primary neutrons are incident on a scatterer made of a fissionable material (U^{238}), neutrons of lower energy are produced both by fission and inelastic scattering, while neutrons of higher energy than the primary neutrons are produced only by fission events. A study of the resulting spectrum between 2.5 and 5 Mev shows that in this energy region the spectrum of fission neutrons produced by 2.45-Mev neutrons incident on U^{238} has the same shape as that produced by thermal fission of U^{235}.[2] If it is assumed that these two fission spectra are also the same in the energy region below 2.5 Mev, then the spectrum of inelastically scattered neutrons from U^{238} can be separated from the composite. This inelastic spectrum has been analyzed in terms of a statistical model and a nuclear temperature obtained. Nuclear temperatures have also been obtained for several other nuclides, and these results will be presented. In addition, a

curve of the 90° differential elastic cross section as a function of atomic weight for about 50 elements will be shown.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] L. Cranberg and J. S. Levin, Bull. Am. Phys. Soc. Ser. II, 1, 56 (1956).
[2] N. Nereson and L. Cranberg, U. S. Atomic Energy Commission Rept. LA-1916, 1955 (unpublished).

F9. Inelastic Collision Cross Sections at 1.75-, 2.50-, 3.25-, and 7-Mev Neutron Energy.* J. R. BEYSTER AND M. WALT, *Los Alamos Scientific Laboratory*.—Inelastic collision cross sections for fast neutrons have been measured by the sphere technique at the foregoing energies. Monoenergetic neutrons were produced by the $H^3(p,n)He^3$ and the $H^2(d,n)He^3$ reactions. At 7 Mev, neutrons were detected by a scintillation detector; a gas-filled proportional counter was used at the other neutron energies. Both detectors were operated at several energy thresholds. Table I gives cross sections obtained at the 80% threshold. Experimental errors in these cross sections are between 5 and 10%.

TABLE I. Inelastic collision cross sections (barns).

Element	1.75 Mev	2.5 Mev	3.25 Mev	7 Mev
Al	0.150	0.38	0.53	0.86
Ti	0.55	0.79	0.98	1.30
Fe	0.74	1.04	1.08	1.41
Zn		1.30		1.61
Zr	0.61	1.17	1.44	1.70
Ag		2.07		2.00
Cd	1.55	1.92	1.95	2.05
Sn	0.73	1.39	1.73	2.00
Au	2.12	2.67	2.59	2.49
Bi	0.41	0.76	1.31	2.38

* Work performed under the auspices of the U. S. Atomic Energy Commission.

F10. Differential Cross Sections for Elastic Scattering of 2.5-Mev and 7-Mev Neutrons.* M. WALT AND J. R. BEYSTER, **Los Alamos Scientific Laboratory**.—Differential cross sections for elastic scattering of fast neutrons were measured at 2.5 Mev for Al, Fe, Zr, Sn, Ta, and Bi and at 7 Mev for Be, C, Al, Fe, Zr, Sn, Ta, and Bi. Monoenergetic neutrons of 2.5 Mev and 7 Mev were produced by the $H^3(p,n)He^3$ and $H^2(H^2,n)He^3$ reactions, respectively. The source neutrons were allowed to strike cylindrical samples of the elements being studied, and the scattered neutrons were detected by energy sensitive counters. A methane-filled proportional counter, biased to have detection thresholds at about 1.2, 1.6, and 2.0 Mev, counted the scattered neutrons at 2.5-Mev incident energy. For an incident energy of 7 Mev a scintillation counter biased to give several thresholds between 4.5 and 6 Mev was used. At both 2.5 Mev and 7 Mev the differential cross sections of all elements were largest at small scattering angles, these forward maxima being more pronounced at 7 Mev than at 2.5 Mev. With the exception of Ta all elements measured at 2.5 Mev had additional maxima for scattering through angles near 180°. At 7 Mev the differential cross sections of most of the elements had one or two secondary maxima at angles between 45° and 135°. Inelastic collision cross sections obtained by subtracting the elastic cross sections from the total cross sections are in good agreement with inelastic collision cross sections reported in the preceding abstract.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

F11. Total Neutron Cross Section of Chlorine, 0.03 to 15 000 ev.* R. M. BRUGGER, J. E. EVANS, E. G. JOKI, AND R. S. SHANKLAND,† *Phillips Petroleum Company*.—The total cross section of chlorine was measured using the materials testing reactor crystal spectrometer (0.03 to 70 ev) and the fast chopper (16 to 15 000 ev). The cross section drops from a value of 44 barns at 0.03 ev to a low of 1.3 barns at 5 kev. A sharp resonance was observed in chlorine-35 at 405±6 ev. A two sample area analysis of this resonance gave the limits $\Gamma<0.6$ ev and $\sigma_0>580$ barns. $\Gamma_n=0.14$ ev for these limiting values. A previously reported resonance[1] was also observed at 8.7 kev. Fitting the cross-sectional data with a single-level Breit-Wigner formula for a negative energy level in chlorine-35, similar to the procedure of Hibdon and Muehlhause,[2] gave preliminary values: $E_0=-127$ ev, $\Gamma_\gamma=0.34$ ev, $\Gamma_n=8.8$ ev, $\sigma_{pot}=1.39$ barns and R(chlorine-35) $=4.73\times10^{-13}$ cm. The spin of the negative level was assumed to be 2. The above value of R gives $R_0=1.44\times10^{-13}$ cm for the equation $R=R_0A^{\frac{1}{3}}$.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Case Institute of Technology.
[1] Toller, Patterson, and Newson, Phys. Rev. 99, 620(A) (1955), and private communications.
[2] C. T. Hibdon and C. O. Muehlhause, Phys. Rev. 79, 44 (1950).

F12. The Coherent Neutron Scattering Amplitudes of Krypton and Xenon, and the Electron-Neutron Interaction.* M. F. CROUCH,† V. E. KROHN, AND G. R. RINGO, *Argonne National Laboratory*.—The coherent scattering amplitudes of krypton and xenon for thermal neutrons have been measured by a comparison method involving reflection of a neutron beam from liquid mirrors. The results were $(7.68\pm0.19)\times10^{-13}$ cm for krypton and $(4.94\pm0.16)\times10^{-13}$ cm for xenon. When these results are used with the scattering measurements of Hamermesh, Ringo, and Wattenberg,[1] one obtains 4500±600 ev and 3100±500 ev, respectively, from their krypton and xenon measurements. Further scattering measurements are planned in order to improve the accuracy of the result for the electron-neutron interaction.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† On summer leave from Case Institute of Technology.
[1] Hammermesh, Ringo, and Wattenberg, Phys. Rev. 85, 483 (1952).

F13. High Resolution Slow Neutron Spectrometer. I. Methods of Level Analysis Using a Self-Indication Detector.* J. RAINWATER, G. GRIMM, AND W. W. HAVENS, JR., *Columbia University*.—Measurements have been made using scintillation detectors to detect resonance capture gamma rays emitted by different thickness foils of the element being studied. Sharp resonance peaks are observed above a relatively smooth background. Transmission measurements are also made using the same thickness foil at the detector and transmission positions. Results for tantalum and silver are presented in the following papers using methods of analysis discussed in this paper to determine the resonance parameters by "thick-thin" sample measurements. Most of the measurements were made for energies $\lesssim 50$ ev where the energy loss on scattering is large compared to the level width, so scattering corrections are relatively unimportant.

* This work was partially supported by the U. S. Atomic Energy Commission.

F14. High Resolution Slow Neutron Spectrometer. II. Results for Tantalum.* G. GRIMM, J. S. DESJARDINS, J. ROSEN, J. RAINWATER, AND W. W. HAVENS, JR., *Columbia University*.—Neutron resonance levels have been observed in tantalum at 35.5, 39.2, 49.1, 57.4, 63.0, 77.0, 77.5, 78.7, 82.7, 85.0, 89.4, 91.2, 103.3. 105.3, 115.3, 117.7, 126.2, 136.2, 138.1, 143.9, 148.1, 149.4, 166.0, 175.1, 194.5, 199.4, 203.8, 207.9, 214.4, 216.1, 219.3, 221.6, 224.5, 229.9, 231.8, 236.4, 241.8, 246.6, 272.2, 275.7 ev energy by the self-indication method. Foils having $1/n=700$ barns/atom and 140 barns/atom were used. Results of the analyses to determine level parameters will be presented. For $E>75$ ev, a much greater density of levels is found than has been previously reported. These measurements were made using a source detector distance of 35.21 m, a source on time ~0.1 μsec and detector gate widths of 0.25 and 0.50 μsec.

* This work was partially supported by the U. S. Atomic Energy Commission.

F15. High Resolution Slow Neutron Spectrometer. III. Results for Silver.* W. W. HAVENS, JR., G. GRIMM, J. S. DESJARDINS, J. ROSEN, AND J. RAINWATER, *Columbia University.*—Self-indication measurements have been made on silver using foils of the element having $1/n = 103.3$ barns per atom and 1450 barns per atom. For these measurements a source detector distance of 35.21 m, source on time of ~0.1 μsec and detector gate widths of 0.25 and 0.50 μsec were used. Levels have been observed at 16.6, 30.4, 40.5, 41.6, 45.0, 51.6, 56.0, 71.2, 88.0, 133.4, 139.6, 143.7, 173, 188, 203, 209, 250, 264, 290, 300, 310, 315, 325, 360 ev. Results of the analysis to determine the resonance parameters will be presented.

* This work was partially supported by the U. S. Atomic Energy Commission.

THURSDAY AFTERNOON AT 2:00

NBS, East Building

(E. BURSTEIN presiding)

Invited Papers in Solid-State Physics

FA1. Antiferromagnetism in Single Crystals. T. R. MCGUIRE, *Naval Ordnance Laboratory.* (30 min.)

FA2. Electron Transport Properties of Dilute Magnesium Alloys. A. I. SCHINDLER, *Naval Research Laboratory.* (30 min.)

FA3. Mechanism of Photoconductivity in the Lead Salts. R. L. PETRITZ, *Naval Ordnance Laboratory.* (30 min.)

FA4. Determination of Crystal Structure from Breakdown Paths. J. W. DAVISSON, *Naval Research Laboratory.* (30 min.)

FA5. Self-Energy and Interaction Energy of Stacking Faults in Metals. JOHN PLASKETT, *University of Virgina.* (30 min.)

THURSDAY AFTERNOON AT 2:00

Sheraton Park, Burgundy Room

(W. H. ZINN presiding)

Apparatus of Nuclear Physics, I

G1. Operating Characteristics of the Helium Bubble Chamber.* E. M. HARTH, M. E. BLEVINS, M. M. BLOCK, M. J. BUCKINGHAM, W. M. FAIRBANK, AND G. G. SLAUGHTER, *Duke University.*—The development of a bubble chamber using liquid helium at 4.2°K and atmospheric pressure was reported previously.[1,2] Several features of this new device have been materially improved. In the present chamber a cylindrical column of liquid helium 1.5 in. in diameter and 4 in. long is expanded by a Teflon piston in contact with the liquid as opposed to the vapor expansion method reported earlier. Volume expansion ratios as low as 1.005 produce tracks, the optimum value being about 1.01. Tracks were photographed in dark field illumination using an improved optical system which obviates the use of baffles while retaining the necessary forward collimation of the light beam. The sensitive time of the chamber has been determined by irradiating the chamber with γ-ray pulses of ~1-millisecond duration. Tracks of excellent quality were formed by ionizing particles traversing the chamber between 0 and 3 milliseconds after the expansion. The characteristic features of this chamber are the high bubble density corresponding to tracks of minimum ionization, the small size of the bubbles even when photographed as much as 20 milliseconds after expansion, the extremely small expansion ratio, and the convenient operating pressure.

* This work was supported in part by the U. S. Atomic Energy Commission, the Office of Ordnance Research, and the Office of Naval Research.

[1] Fairbank, Harth, Blevins, and Slaughter, Phys. Rev. **100**, 971 (A) (1955).

[2] Harth, Fairbank, Blevins, and Slaughter, Proc. of the International Conference on Low Temperature Physics, Paris, 1955 (to be published).

G2. Millimicrosecond Pulsing of the BNL Research Electrostatic Accelerator.* S. D. BLOOM AND C. M. TURNER, *Brookhaven National Laboratory.*—Ion current pulses in the millimicrosecond range are being produced for time-of-flight experimentation with the BNL research electrostatic accelerator by sweeping the ion beam inside the terminal across a ¼-in. diameter limiting aperture at its point of entry into the acceleration tube. This method of producing short pulses has two outstnading advantages[1] over sweeping a steady beam external to the accelerator: (1) the production of background radiation is minimized; (2) the peak pulse intensity can be many times greater than that of a steady beam, since an acceleration tube is sensitive to average current rather than peak pulse current. Preliminary performance data is comparable to that of the Oak Ridge group.[2] Full width at half-maximum of the pulse was measured to be ~7 mμ by techniques described elsewhere.[3] The recurrence period was 58 mμ and the average current from 1 μa–2 μa.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] C. M. Turner, BNL Memorandum, 1951 (unpublished).

[2] Neiler *et al.*, Bull. Am. Phys. Soc. Series II, **1**, 70 (1956).

[3] S. D. Bloom, Phys. Rev. **98**, 233 (1955).

G3. Acceleration through Phase Transition in the Brookhaven Electron Analog.* E. C. RAKA, R. R. KASSNER, M. PLOTKIN, AND J. SPIRO, *Brookhaven National Laboratory.*—The radio-frequency system of the electron analog employs a signal from the circulating beam as the frequency determining element and uses radial position information to control the phase of the accelerating gap voltage.[1,2] This system has successfully carried the beam from the injected energy of 1 Mev to a final energy (≈6 Mev) well beyond the phase transition energy of 2.7-Mev kinetic. In the transition energy region the

phase of the rf voltage is rapidly advanced and the sense of the radial correction signal reversed. No significant loss of beam intensity occurs in traversing the phase neutral region. With the aid of programmed correcting fields, it is possible to accelerate more than 50% of the initially accepted injected beam for the full cycle. The favorable beam survival plus the successful operation through the phase transition region indicates the suitability of this type of rf system for alternating gradient machines.

* Work carried out under contract with U. S. Atomic Energy Commission.
[1] Cottingham, Plotkin, and Raka, Trans. of the Inst. Radio Engrs. Professional Group on Nuclear Science NS-1, 12 (1954).
[2] Cottingham, Christofilos, Plotkin, Raka, and Rhéaume, Phys. Rev. 100, 1269(A) (1955).

G4. Calculations on the Acceleration of Particles in Fixed Field Accelerators.* A. M. Sessler, *Ohio State University*, J. N. Snyder, *University of Illinois*, and K. R. Symon, *University of Wisconsin and Midwestern Universities Research Association*.—In order to investigate the properties of particles subject to radio-frequency acceleration in fixed field accelerators[1] a rather flexible program has been developed for the Electronic Digital Computer of the University of Illinois ILLIAC). The coupling of the phase motion with the betatron oscillations is ignored, but the effect of an arbitrary number of oscillators with arbitrary voltage and frequency programs is included. The particle frequency as a function of energy may also be chosen. It takes the ILLIAC approximately 7 sec to calculate the passage of a particle through 100 oscillators. The program is being used to study the size and shapes of stable zones in synchrotron phase space as a function of particle energy. Acceleration through the transition energy, and the feasibility of various proposed radio-frequency acceleration schemes will be discussed. Comparisons will be made between these results and the theory of particles in fixed field accelerators.

* Supported by the National Science Foundation and the Office of Naval Research.
[1] K. R. Symon, Phys. Rev. 98, 1152(A) (1955).

G5. Axial Motion in the Spirally Ridged FFAG Accelerator.* F. T. Cole, *State University of Iowa*, L. J. Laslett, *Iowa State College*, and J. N. Snyder, *University of Illinois and Midwestern Universities Research Association*.—We have examined analytically the character of small amplitude betatron oscillations about the equilibrium orbit of the spirally ridged accelerator[1] in greater detail than reported previously.[2] The frequencies of betatron oscillations are predicted from the coefficients in the equations of motion through the aid of tables computed for linear equations of the Hill type. Approximate dynamical equations, not limited to small amplitude motion, were also integrated with the Electronic Digital Computer of the Graduate College of the University of Illinois (ILLIAC) for a variety of machine parameters characteristic of small or model-sized structures. The last-mentioned work not only affords a check of the predicted features of small amplitude oscillation, but also permits a survey to be made of the axial limits of stable oscillation. The results of such a survey for the axial motion will be presented, supplementing work reported previously[3] for the radial motion.

* Assisted by the National Science Foundation and the Office of Naval Research.
[1] Kerst, Terwelliger, Symon, and Jones, Phys. Rev. 98, 1833(A) (1955).
[2] L. J. Laslett, Phys. Rev. 99, 653 (A) (1955).
[3] Cole, Laslett, and Snyder, Bull. Am. Phys. Soc. Series II, 1, 61 (1956).

G6. Methods for Radio-Frequency Acceleration in FFAG.* K. R. Symon, *University of Wisconsin*, and A. M. Sessler, *Ohio State University and the Midwestern Universities Research Association*.—Fixed field accelerators and particularly FFAG accelerators permit a wide variety of acceleration schemes. If accelerator gaps are driven at radio frequency which may or may not be synchronized, then in the neighborhood of each energy for which the frequency of revolution of the particles is equal to the radio frequency or any of its subharmonics, there is a region of particle energies and phases ("bucket") within which particles execute stable phase oscillations around the synchronous energies. If the radio frequency is modulated, the "buckets" move up or down the energy scale. Under suitable conditions, particles in any of these buckets can be accelerated by this process. Phase displacement acceleration is also possible in which the frequency modulation is reversed from the normal direction so that empty buckets move down the energy scale and particles outside the bucket are accelerated upward. One can classify acceleration schemes as scheduled or unscheduled according to whether or not the various radio frequencies follow a synchronized program so that you accelerate every particle according to a definite schedule. Thus a wide variety of schemes are available, each with its particular advantages and disadvantages.

* Supported by the National Science Foundation and the Office of Naval Research.

G7. Constant Frequency Multi-Bev FFAG Accelerators.* Lee C. Teng, *Argonne National Laboratory*.—In the linear theory, the number of radial and axial betatron oscillations per revolution, ν_x and ν_z, for an FFAG ion accelerator with a median plane are given as power series in $1/N^2$(N = number of sectors). The zeroth-order terms of these series give readily the existing approximate focusing conditions for a Thomas cyclotron, a spirally ridged FFAG accelerator, or an AG synchrotron. Among other features of the higher order terms, the coefficient of $1/N^2$ in ν_x^2 contains a term proportional to the radial gradient of the flutter. With specific choices of the radial dependence of the flutter the $1/N^2$ term can be made either positive or negative. This indicates that constant frequency cyclotrons can be designed for energies much higher than one rest energy of the ion without crossing the $\nu_z = 2$ resonance, and that constant frequency FFAG ring accelerators with fixed operating values of ν_x and ν_z can be designed to accelerate ions over a wide energy span. Together with the proposed scheme[1] of transferring protons at Bev energies between circular accelerators, constant frequency FFAG proton accelerators for energies up to 100 Bev are feasible.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] L. C. Teng, Phys. Rev. 100, 1247 (1955).

G8. An Analytical Method for Correcting the Magnetic Field of a Cyclotron.* James A. Baker and Warren Fenton Stubbins, *University of California, Berkeley*.—A computational procedure has been devised to give the shim changes required to correct the magnetic field of the 184-in. cyclotron, thus avoiding the empirical shimming formerly used. A mathematical model of the shim element suggested by Lambertson's study of the effect of small volumes of iron on the pole faces of magnets was used. The magnetic field is described by stating its value on the median plane above the 240-shim element centers. A mapping function, calculated from the induced dipoles and their images, which gives the effect on the magnetic field in the median plane for a unit change in the height of each of 240 shim elements was computed. The effect of each shim element change in the 23 000-gauss field is determined for all centers. By an iterative process, 240 simultaneous equations are solved to find the necessary shim element changes. Those calculated for a large measured field change corresponded to the ones producing the change in the 184-in. model magnet. The application of this method to shimming the 184-in. cyclotron will be reported.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

G9. Livermore Variable-Energy Cyclotron. I. Magnet.* Charles J. Taylor, Alexander Bratenahl, H. Paul Hernandez, Jack M. Peterson, Bob H. Smith, and Ralph

H. STAHL, *University of California, Livermore.*—The Livermore cyclotron was designed to accelerate ions to final energies in the following energy ranges in Mev: protons 2.5–15, deuterons 5–12.5 tritons 7.5–8.5, alpha particles 10–25. This is accomplished by changing both the magnetic field and the frequency. The magnet has a nominal radius of 45 in., an extraction radius of 35 in., and is operated over the range of 2.5 to 8.5 kilogauss. The direction of the magnetic field is horizontal. The magnetic gap is 12 in. at the center, increased by 60 mils at 35 in. radius. Shimming was accomplished by machining the pole faces and adding a few edge shims. The pole faces are within the vacuum. The magnet contains 300 tons of steel and 8.5 tons of copper. The field falloff is closely linear and at extraction is 1% below central field. First harmonics in the field are less than 0.05%; "*n*" increases linearily to 0.01 at extraction radius. A cam-shaped radial extension to the field permits extraction of the beam from the magnetic field in a direction perpendicular to the constant field contours.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

G10. Livermore Variable-Energy Cyclotron. II. Radio-Frequency.* ALEXANDER BRATENAHL, H. PAUL HERNANDEZ, JACK M. PETERSON, B. SMITH, RALPH H. STAHL, AND CHARLES J. TAYLOR, *University of California, Livermore.*—The dee frequency is determined by a crystal-controlled oscillator variable in 55-kilocycle steps from 4 to 9.5 megacycles.[1] The power amplifier with an RCA 2332 tube in the final stage delivers up to 150 kilovolts dee voltage. A single dee hangs between ground planes whose spacing from the dee can be changed remotely. The dee cavity is matched to the oscillator frequency by adjusting the dee-to-ground spacing and inserting or removing a fixed-position shorting spider. Fine tuning of the dee cavity is accomplished by an automatic servo-driven trimming capacitor. A dc deflector, made in two sections and operating at a maximum of 140 kilovolts, extracts the beam into the magnetic cam region. A conventional hooded ion source is used. The aluminum vacuum tank, 12 by 14 by 2 ft, is evacuated by two 32-in. mercury diffusion pumps.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] Bob H. Smith, "A 90-inch cyclotron with an adjustable-energy external beam," UCRL-2620, June, 1954.

G11. Livermore Variable-Energy Cyclotron. III. Performance.* RALPH H. STAHL, ALEXANDER BRATENAHL, JAMES A. GALVIN, ROY K. MULLINS, JACK M. PETERSON, AND CHARLES J. TAYLOR, *University of California, Livermore.*—Protons, deuterons, and alpha particles have been accelerated at a number of frequencies within the available frequency range. Extracted beams have been obtained. Performance data and neutron production by acceleration of protons and deuterons onto a tritium gas target will be given.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

G12. A Microtron Injector for Electron Synchrotrons with Straight Sections. II. H. F. KAISER, *Naval Research Laboratory.*—In a previous paper[1] a 5-Mev microtron injector was described. Here the method of passing the ejected beam into the straight section will be described further. The method followed is to pass the ejection beam across the center line of the straight section and arrange the "step-off" lip so that the ejection beam leaves at an angle to the center line which it intersects at a design point. The intersection is virtual since a pole area of opposite polarity to the microtron field is utilized in the region to bend the ejection beam into the center line, thus meeting the first requirement of on-orbit injection. The beam after completely traversing the synchrotron circuit is deviated by a second magnet field area on the opposite side to steer the "circuit" beam into the fringe field of the microtron. It may be shown that this beam may be brought to a common focus with the ejection beam at the design point. The field of the "exit" bender magnet may, therefore, be designed to bring these rays into close parallelism on the center line. By time variation of the "bender" fields effects of changes in circuit equilibrium orbit position with time may be compensated.

[1] H. F. Kaiser, Phys. Rev. **100**, 1246(A) (1955).

G13. Operation of a Linear Electron Accelerator at High Current. W. G. WADEY AND L. ROSLER, *Yale University.*—The operating characteristics of the Yale linear electron accelerator as presently extended will be described. It is presently operating at about 6.5 Mev with a peak current of about 200 ma. The limitation is no longer the electron gun but the beam loading of the first cavity which will be described and discussed.

G14. Controlled Gradient Cylindrical Electrostatic Lens System for Charged Particle Deflection.* R. C. MOBLEY, *Louisiana State University.*—In an effort to avoid the complications associated with Fourier synthesis, a new wide aperture controlled gradient cylindrical electrostatic lens system has been designed to convert an initial easily generated high-frequency sinusoidal ion beam deflection into the essentially linear sweep required for a magnetic deflection-type ion Buncher. The lens is constructed from two stacks of parallel rectangular insulated metal plates with the individual plates aligned essentially parallel to the ion beam and with the stacks orientated parallel to the ion-beam deflection plane but slightly separated to permit the ion beam to pass between. Proper and separate adjustment of the voltage on each of the metal plates permits establishment of a gradient distribution across the lens in the ion deflection plane of a form which will produce additional deflections of the ion beam as it passes through various portions of the lens tailored at each point to convert the initial sinusoidal deflection at the lens into the required essentially linear sweep required at the bunching magnet.

* Supported in part by the U. S. Atomic Energy Commission.

THURSDAY AFTERNOON AT 2:00

Sheraton Park, Grand Ballroom

(H. D. SMYTH presiding)

Addresses by the 1956 Nobel Laureates in Physics

H1. Fine Structure of Nonmetastable States of Hydrogen by a Microwave-Optical Method. W. E. LAMB, *Stanford University.* (45 min.)

H2. (A) Velocity Analyses of Molecular Beams. (B) The Hyperfine Structures of the Hydrogens in the 2*S* State. P. KUSCH, *Columbia University.* (30 min.)

Post-Deadline Papers, If Any

THURSDAY AFTERNOON AT 2:00

Sheraton Park, Caribar-Mural Room

(G. F. CHEW presiding)

Theoretical Physics, II: Nuclear Theory

HA1. An Interpretation of the $Be^9(d,d)$ Reaction at Low Energies.* S. GLASHOW AND W. SELOVE, *Harvard University.*—The angular distribution of the $Be^9(p,d)$ reaction has been measured recently at several energies between 5 and 31 Mev and is seen to be substantially constant. This result is in disagreement with the Butler theory, from which one would expect a diffraction like result with minima occurring at angles which depend strongly upon energy. As a result of the weak binding of the picked-up neutron of Be^9 it may be expected that the Born approximation with no restriction of the region of integration ("transparent nucleus") would be more applicable than the Butler theory. Such a theory yields a simple relation between the cross section and the momentum distribution of the picked-up neutron. For incident energies between 16 and 31 Mev a momentum distribution is consistently defined which agrees quantitatively with that obtained from 95-Mev data as well as with a numerical solution to the Schroedinger equation with a reasonable potential. At lower energies (5 and 8 Mev) the theory does not appear to work quite as well. These results support the general validity of interpreting results of the high-energy pick-up process in terms of a momentum distribution and a single particle model.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

HA2. Photodisintegration of Be^9.* C. B. MAST AND C. J. MULLIN, *University of Notre Dame.*—Shell model calculations of the cross section for the electric dipole photodisintegration cross section of Be^9 have been made using $L-S$, $j-j$, and intermediate coupling. The energy is assumed to be below the (γ,p) threshold. The two peaks[1] in $\sigma(\hbar\omega)$ are associated with even parity levels in Be^9 at 1.8 and 4.8 Mev. These excited levels are assigned a p^4s (or p^4d) configuration. When a neutron is decoupled from this configuration, the Be^8 core is left in either the $p^4(J=0)$ ground level or the $p^4(J=2)$ first excited level. The ratio $R=\sigma(Be^9\rightarrow Be^{8*})/\sigma(Be^9\rightarrow Be^8)$ depends upon the intermediate coupling parameter $\zeta=a/K$. When both reactions are energetically permitted, R increases as one passes from the $L-S$ to the $j-j$ limits. The value $R=1.7$, in reasonable agreement with the experimental results of Carver, Kondaiah, and McDaniel,[2] is obtained with $\zeta=1.4$.

* Supported in part by the Office of Naval Research.
[1] E. Guth and C. J. Mullin, Phys. Rev. **76**, 234 (1949).
[2] Carver, Kondaiah, and McDaniel, Phil. Mag. **45**, 948 (1954).

HA3. Alpha-Particle Model for C^{12}. A. E. GLASSGOLD, *University of Minnesota,* AND A. GALONSKY, *Oak Ridge National Laboratory.*—The α-particle model for C^{12} has been re-examined. Starting with the rotation-vibration states of an equilateral triangle model,[1] the energy depends on three parameters, a moment of inertia and two normal vibration frequencies. Two possible correlations of the observed levels are possible at present. The two identifications are identical

Energy (Mev)	0	4.43	5.53	7.65	7.77	9.61
a	0^+	2^+	3^-	0^+	none	1^-
b	0^+	2^+	3^-	0^+	1^-	2^+

up to 7.65 Mev and correctly correlate the known states at 4.43 Mev (rotational) and 7.65 Mev (nondegenerate vibrational). The nature of the 4.43-Mev state implies a 3^- rotational state at 5.53 Mev which has never been observed. The two alternatives arise for the 9.61-Mev state because its spin and parity are not definitely known. Scheme b places a 1^- level at 7.77 Mev. Such a level would probably be difficult to detect. No comparison is possible at higher excitation because of insufficient knowledge about spins and parities. The parameters agree with those obtained for O^{16}.[2]

[1] J. A. Wheeler, Phys. Rev. **52**, 1083 (1937).
[2] D. M. Dennison, Phys. Rev. **96**, 378 (1954).

HA4. Two-Level Fit to Two Interfering $1/2+$ States in N^{15}. A. J. FERGUSON AND H. E. GOVE, *Chalk River Laboratories.*—Two interfering $1/2+$ levels observed in the proton bombardment of C^{14} at proton energies of 1.31 Mev and 1.50 Mev[1] have been studied in relation to Wigner's two-level resonance formula.[2] A good fit to the (p,γ) and (p,n) yields has been found which conforms with the formula. The parameters which have been found for the laboratory system are:

Proton energy Mev	Γ_p kev	Γ_n kev	Γ_γ ev
1.31	15.0	24.4	2.4
1.50	506	18.4	26.3

These are computed at the resonance energies.

[1] Bartholomew, Brown, Gove, Litherland, and Paul, Can. J. Phys. **33**, 441 (1955).
[2] E. P. Wigner, Phys. Rev. **70**, 606 (1946).

HA5. Gamma Transition Widths in the $1p$-Shell.* D. KURATH, *Argonne National Laboratory.*—The calculation of properties of nuclei in the $1p$-shell with intermediate strength of spin-orbit coupling[1] has been extended to include some gamma transition widths. Experimentally observed resonances in Be^8, B^{11}, and C^{12} have been computed. It is found that while the $M1$ transition widths give reasonable values, the $E2$ transition widths as computed with this model are sometimes too small.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Dieter Kurath, Phys. Rev. **101**, 216 (1956).

HA6. Eu^{153}, Gd^{155}, and the unified Model.* E. L. CHURCH,† *Brookhaven National Laboratory.*—The low-lying level structures of Eu^{153} and Gd^{155} have been studied[1] following beta decay of Sm^{153}, Gd^{153}, and Eu^{155}. When analyzed with the help of the calculations of Rose *et al.*,[2] the L-conversion patterns of the 83.3-kev transition in Eu^{153} and the 59.8-kev transition in Gd^{155} are consistent with $M1+E2$ mixtures, with gamma ratios $M1/E2<1$ and $M1/E2\sim16$, respectively. These transitions are assumed to be identical with the rotational transitions observed following Coulomb excitation of these nuclei. In terms of the unifield model, these mixing ratios are interpretable in terms of the gyromagnetic ratios of the core and particle structures. The absolute and relative conversion properties of the 97.3-kev transition in Eu^{153}, and the 86.3- and 105.1-kev transitions in Gd^{155}, show that these transitions are $E1$. Their lifetimes are $<10^{-6}$ second. The presence of such low-lying odd-parity transitions is contrary to the predictions of the simple shell model, but may be related to the drastic modification of particle levels in a deformed core. Tentative level schemes are proposed, and the present results and the known properties of the ground states correlated in terms of the unified model.

* Work supported in part by the U. S. Atomic Energy Commission.
† On leave from Frankford Arsenal, Philadelphia, Pennsylvania.
[1] E. Church and M. Goldhaber, Phys. Rev. **95**, 626 (1954).
[2] Rose, Goertzel, and Swift (private communication, 1955).

HA7. Electric-Monopole Transitions in 0-2-2 Nuclei.* J. WENESER,† *University of Illinois*, AND E. L. CHURCH,‡ *Brookhaven National Laboratory*.—If electric-monopole matrix elements $\rho \equiv \langle i | \sum (r_p/R)^2 | f \rangle$ were of the order of unity, monopole conversion would be readily observable[1] in the $2+ \rightarrow 2+$ transitions in heavy 0–2–2 nuclei.[2] Experimental data on such transitions in Pt^{192}, Pt^{196}, and Hg^{198}, however, show no noticeable monopole components, corresponding to *upper limits* on ρ of between 1/10 and 1/40. Estimates of monopole matrix elements for an incompressible nucleus have been made on the basis of the collective models[2,3] designed to explain other properties of 0–2–2 nuclei. If the monopole operator is written as a power series in the collective deformation parameter $\alpha_{2\mu}$, it is found that nonvanishing contributions to the matrix elements come only from higher order terms, corresponding to values of ρ an order of magnitude smaller than the present experimental upper limits. These models also predict $0+$ excited states in these even-even nuclei. Depending on the character of the higher $0+$ state, the $0+ \rightarrow 0+$ monopole transitions to the ground state may proceed via lower order terms than the $2+ \rightarrow 2+$ transitions, and hence exhibit moderate matrix elements.

* Work supported in part by the U. S. Atomic Energy Commission.
† On leave from Frankford Arsenal, Philadelphia, Pennsylvania.
‡ On leave from Brookhaven National Laboratory.
[1] E. Church and J. Weneser, Phys. Rev. **100**, 934 (1955).
[2] G. Scharff-Goldhaber and J. Weneser, Phys. Rev. **98**, 212 (1955).
[3] L. Wilets and M. Jean, Phys. Rev. (to be published).

HA8. A Radiative Correction to the Theory of Alpha Decay. H. C. CORBEN, *Carnegie Institute of Technology*.—Polarization of the vacuum by the Coulomb fields of an α particle and its parent nucleus causes the mutual potential energy of the two charges to be increased, in the tunneling region, by an amount which is of the order of an $l=1$ angular momentum barrier but which is of longer range. Such a modification of the Coulomb barrier would as much as double the half-life, the effect being larger for lower energy α particles, so that to neglect it would cause the nuclear radius to be underestimated by about one percent. The effect is masked, however, both by theoretical and experimental uncertainties in α decay and by the fact that it is common to all α emitters, even for different l.

HA9. Tensor Forces and Intermediate Coupling. ARNOLD M. FEINGOLD, *University of Illinois*.—The tensor force contribution to the binding energy of Li^6 and Li^7 is about 12 Mev,[1] and it can be expected to be larger for heavier nuclei. Low-lying states are thus essentially degenerate with respect to the tensor force which then may produce large mixing of the low states even in the absence of direct tensor matrix elements between them.[2] The type of coupling among the low states resulting from this near degeneracy has been investigated by using perturbation theory, the high-lying states which are mainly responsible for the tensor force effects being eliminated by closure. An intermediate coupling model emerges which is similar to the customary one,[3] in that the *effective* nuclear potential for the low states is shown to consist of a central force, a strong vector force, and a weakened tensor force. Distinctive features of this coupling model, and some properties of the effective vector force, which is mainly a three-body force,[1] will be discussed.

[1] A. M. Feingold, Phys. Rev. **101**, 258 (1956).
[2] A. M. Feingold and E. P. Wigner, manuscript on β decay, 1948 (unpublished).
[3] D. R. Inglis, Revs. Modern Phys. **25**, 390 (1953).

HA10. Some Remarks on Model Operators. N. FUKUDA, *Indiana University*.*—The theory of nuclear models discussed by Eden and Francis[1] is reformulated from somewhat different points of view. They introduce the model Hamiltonian from the beginning and intend to determine the potential from the self-consistency requirement. However, it is not quite clear whether this self-consistent problem has a solution at all. Furthermore, the meaning of the model operator seems to be ambiguous when we treat many nuclear levels. Our way of approach is first, to introduce the model space M of arbitrary dimension m which is composed of some simple wave functions; second, to transform the original Schroedinger equation into that in the model space; third, to obtain the integral equation for the model operator which determines the model Hamiltonian. This equation does no longer contain the exact eigenvalue as is the case in the above mentioned work, and is shown to have a unique solution in some cases. The m excited states of the nucleus can in principle be treated in this formalism. The independent-particle model will be treated as an illustration.

* Supported in part by a grant from the National Science Foundation.
[1] R. J. Eden and N. C. Francis, Phys. Rev. **97**, 1365 (1954).

HA11. Effects of Nuclear Correlation Structure on the Imaginary Part of the Weisskopf Potential.* K. A. BRUECKNER, *Brookhaven National Laboratory*.—The imaginary part of the potential acting on a neutron moving in the nucleus is shown to be very sensitive to the departure of the nuclear ground-state wave function from that of an independent particle model. The nucleon-nucleon interaction which gives rise to the neutron absorption also leads to correlation structure in the nuclear wave function. This manifests itself both in the partial emptying of the independent particle states near the Fermi momentum and in the velocity dependence of the real part of the average potential seen by the neutron. These effects are determined using interaction operators derived in studies of the nuclear saturation problem. The result is that the velocity dependence of the potential reduces V_{1m} by a factor of about eight; the departure of the nuclear state from complete degeneracy gives an increase of roughly 5 in the opposite direction. Thus, the two effects nearly cancel so that the final prediction for V_{1m} at a density corresponding to $R=1.40+10^{-13}A^{\frac{1}{3}}$ cm is close to the empirical value. It is also found that V_{1m} decreases rapidly for higher nuclear densities, suggesting that the neutron absorption may be primarily a surface phenomenon.

* Under contract with the U. S. Atomic Energy Commission.

HA12. Effects of the Exclusion Principle on the Self-Consistent Solution of the Nuclear Many-Body Problem.* W. W. WADA† AND K. A. BRUECKNER, *Brookhaven National Laboratory*.—The two-body reaction matrix has been found in saturation studies to be of fundamental importance in determining the energy and density of nuclear matter. The effects of the velocity dependence on the nuclear potential have previously been taken into account[1]; we have now determined the correction to the reaction matrix which results from the action of the exclusion principle. A variational expression for the reaction matrix is used in which the trial wave function has been taken to be the solution which is exact if exclusion effects are neglected. The correction due to the exclusion effect is most important for low relative momenta, reducing the reaction matrix at normal density by about a factor of two at $k=0$. The effect decreases rapidly as the relative momentum increases, falling to about 15% at 1/2 the Fermi momentum. Although the effect is thus not unappreciable, it is partially compensated by a slight increase in the effective nucleon mass which is required to obtain a self-consistent solution. The net shift in the nuclear binding energy per particle is of the order of one or two Mev. More detailed results for the binding energy and density will be discussed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† On leave of absence from the U. S. Naval Research Laboratory.
[1] K. A. Brueckner, Phys. Rev. **97**, 1353 (1955).

HA13. A Test of the Statistical Assumption in Nuclear Reactions.* N. M. HINTZ AND R. M. EISBERG, *University of Minnesota*.—The angular distributions of protons inelastically

scattered from discrete states of nuclei will be symmetric about 90° providing: the reaction goes through the compound nucleus (compound nucleus assumption), many levels are excited in the compound nucleus (continuum assumption), the phases of these levels are random (statistical assumption). The observed departure from symmetry of such angular distributions, in situations where the continuum assumption is probably satisfied, is usually attributed to a violation of the compound nucleus assumption, i.e., to the presence of direct interaction. However, it also could be the result of a violation of the statistical assumption. It may be possible to distinguish between these alternatives by measuring angular distribution at several closely spaced bombarding energies.[1] A sensitive dependence of the angular distributions on bombarding energy would be difficult to explain if the departure from symmetry were due only to a violation of the compound nucleus assumption, but would be easy to explain if the statistical assumption were violated. We have measured the angular distribution for $A^{40}(p,p')A^{40*}$, to the 1.47-Mev level, at bombarding energies of 9.7, 9.0, and 8.5 Mev. Significant changes in the asymmetric angular distributions are observed.

* Supported in part by the U. S. Atomic Energy Commission.
[1] R. M. Eisberg, Brookhaven Conference on Statistical Aspects of the Nucleus, BNL 331, page 85 (1955).

FRIDAY MORNING AT 9:00

Sheraton Park, Burgundy Room

(J. B. H. KUPER presiding)

Apparatus of Nuclear Physics, II

J1. Separating Effect in the Magnetoionic Expander Isotope Separator. JOSEPH SLEPIAN, *Westinghouse Research Laboratories.*—Ions and electrons in equal numbers, generated by a very short arc, in a parallel magnetic field, enter the separator and are also subjected to a difference of electric potential between the diverging side walls. Few ions and electrons are caught on either side wall due to the deflection of the magnetic field, but they are nearly all caught on the insulated end slats terminating the large end of the expander. Since the deflection in a magnetic field alone is proportional to the ratio of the velocity to the mass v/m, of a particle only, whereas the effect of an electric field alone is determined by its change in energy, $1/2\ mv^2$, only, there occurs a separating effect between the isotopes caught on the various end slats. The entering ions and electrons have an equal high random or thermal energy, but as they proceed up the expander their uniform velocity increases and their random or thermal energy approaches zero. The disappearance of the random energy causes the different isotopes to deposit on the different slats, the enrichment being approximately $(L/L_0)^2\frac{1}{2}(\delta m/m)$. There is no limit known to current of ions and electrons in the discharge.

J2. Spectrum of Betatron Target Radiation.* A. SIRLIN, *Cornell University.*—The angular distribution of betatron target radiation was studied on the basis of Schiff's energy-angle distribution for the radiated photons and Molière's complete multiple scattering theory for the incident electrons.[1] New calculations concerning the shape of the spectrum at small angles about the incident direction are being conducted on the basis of a Gaussian approximation for multiple scattering, for the case in which the characteristic width μ/E_0 of the bremsstrahlung distribution is small in comparison with the width of the multiple scattering distribution. For angles θ large in comparison with μ/E_0, it is a well-known theoretical prediction that the shape of the spectrum is roughly independent of angle and is given approximately by the integrated spectrum of Schiff's intrinsic distribution. This, however, is not a good approximation when $\theta \lesssim \mu/E_0$. Due to the logarithmic peak of the scattering distribution at $\theta=0$, corrective terms arise which modify the shape of the spectrum appreciably, especially for low-energy quanta. The resulting angular dependence of the spectrum at small angles will be exhibited graphically.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission. The right to reproduce in whole or in part is granted to the U. S. Government.
[1] A. Sirlin, Phys. Rev. **101**, 1219 (1956).

J3. Polarization of Bremsstrahlen.* JOHN M. DUDLEY, FRED W. INMAN, AND ROBERT W. KENNEY, *University of California, Berkeley.*—The polarization of 6±2-Mev photons in the 24-Mev bremsstrahlung beam of the Stanford Mk II electron linac has been observed, and the angular dependence of the polarization has been measured. The polarization detector utilized the dependence of deuteron photodisintegration upon polarization, and consisted of D_2O-loaded Ilford C.2 emulsions placed directly in the bremsstrahlung beam. The results agree only qualitatively with the theory.[1-3] For a 1-mil thick aluminum radiator, the preliminary values of photon polarization (May's definition) are $P(\theta_0)=0.242\pm0.081$, $P(1.6\theta_0)=0.157\pm0.095$, and $P(2.5\theta_0)=0.123\pm0.102$. Here $\theta_0=1/48$. Comparison of results with the theory and with previous work[4-7] will be made. The authors wish to thank the Hanson High Energy Physics Laboratory, Stanford University, for the use of and help with the accelerator.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] M. May and G. C. Wick, Phys. Rev. **81**, 628 (1951); Michael M. May, Phys. Rev. **84**, 256 (1951).
[2] Gluckstern, Hull, and Breit, Phys. Rev. **90**, 1026 (1953); R. L. Gluckstern and M. H. Hull, Jr., Phys. Rev. **90**, 1030 (1953).
[3] Robert Karplus and Alfred Reifman, "Polarization of Bremsstrahlung," UCRL-2686, September, 1954.
[4] K. Phillips, Phil. Mag. **44**, 169 (1953).
[5] E. G. Muirhead and K. B. Mather, Australian J. Phys. **7**, 527 (1954).
[6] Christophe Tzara, Compt. rend. **239**, 44 (1954).
[7] J. W. Motz, Bull. Am. Phys. Soc. Series II, **1**, 10 (1956).

J4. Gas Scintillation Fission Counters.* K. E. LARSSON,† R. L. ZIMMERMAN, AND H. PALEVSKY, *Brookhaven National Laboratory.*—A gas scintillation counter for the measurement of fission events in plutonium has been in operation for several months at Brookhaven. The counter consists of two phototubes, inserted at either end of an aluminum cylinder, and held by "O" rings. The foil is placed between the phototubes parallel to the axis of the cylinder. The counter is filled to one atmosphere with spectroscopically pure xenon. After filling, the fission and α pulse heights are observed to diminish with about an 8-day period. By using a dry ice-acetone trap at the filling tube the period increases to $\geq$70 days. Two types of phototube arrangements have been used. (1) No. 6292 phototubes with a color shifter of 20 mg/cm² of *p*-quaterphenyl evaporated on the face of each tube.[1] (2) Quartz window-type No. 5819 phototubes using no shifter. Both arrangements exhibited the same time dependence for the pulse size proving that the color shifter was not the principal source of contamination. In both arrangements the ratio fission pulse height to α pulse height was the same ($\sim$20), indicating that both

fission and α particles excite the optical levels of xenon in the same way.

* Work performed under contract with U. S. Atomic Energy Commission.
† Guest scientist from AB Atomenergi, Stockholm, Sweden.
[1] We are indebted to Dr. Ralph Nobles of Los Alamos Scientific Laboratory for preparing these surfaces.

J5. Scintillator Temperature Coefficients.* WILLIAM P. BALL, REX BOOTH, AND MALCOLM H. MACGREGOR, *University of California, Livermore.*—Temperature coefficients as a function of temperature were measured for NaI(Tl), anthracene, stilbene, and plastic over the range 5°C to 40°C. Cesium-137 gamma or conversion electron peaks were used to measure the coefficients of scintillator-plus-photomultiplier systems. The temperature coefficient of the RCA 6199 photomultiplier tube was measured separately by means of a gated cathode-ray tube light-pulse generator. A subtraction then gave the coefficients of the scintillators. Average coefficients in percent change in pulse height per degree centigrade over the foregoing range of temperatures are as follows: anthracene, -0.47 ± 0.03; plastic, -0.29 ± 0.03; stilbene, -0.19 ± 0.03; NaI(Tl), -0.06 ± 0.03; RCA 6199 photomultiplier, -0.22 ± 0.02. The temperature coefficients are nonlinear functions of the temperature, with the exception of anthracene, which is constant over the range 5°C to 28°C. A check of six photomultiplier tubes gave temperature coefficients ranging from -0.2 to $-0.5\%/°C$. An examination of the photomultiplier noise spectrum revealed that the pulse-height distribution changed very slightly over the foregoing range, while the number of noise pulses increased by more than a factor of ten.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

J6. A Technique for Determining the Performance of Liquid Scintillators under a Controlled Atmosphere.* R. K. SWANK AND W. L. BUCK, *Argonne National Laboratory.*—An apparatus has been developed in which liquid scintillators can be studied under a controlled atmosphere. The concentration of any one constituent can be varied while the liquid is maintained under an atmosphere of any desired gas. This apparatus has been used to study the effect of oxygen quenching on a number of liquid scintillator systems. It has been found that both the solvent and solute are quenched by oxygen in all the cases studied. The quenching of toluene by oxygen is greater than the quenching of most solutes by oxygen, but the effect of the solute quenching is the more important factor from a practical viewpoint. Observations are being made of the quenching of liquid scintillators by heavy elements under argon atmosphere. Preliminary results of the latter investigation will be reported.

* Work performed under the auspices of U. S. Atomic Energy Commission.

J7. A Fast Oscilloscope for Scintillation Pulses.* R. M. SUGARMAN, *Brookhaven National Laboratory.*—A sampling oscilloscope[1] has been developed for the study of transient wave forms in the millimicrosecond region. The amplitudes of similar repetitive pulses are sampled at one point at a time, the sampling time being delayed with respect to the start of the pulse in small increments. The resulting samples are stretched and displayed on a conventional oscilloscope whose horizontal deflection is linearly related to the sample time delay. The samples are obtained by gating a microwave diode, a similar diode being used for final shaping of the gating pulse. For a mercury switch pulse the observed rise time is 6×10^{-10} sec. The sensitivity is limited only by the input noise, which is equivalent to a few millivolts of signal, but can be reduced by sample averaging. Photomultiplier pulses have been studied by using a kicksorter to select for display pulses of like amplitude. Using Co^{60} and a fast phosphor, the statistical dispersion does not appreciably smear the wave form, indicating that under these conditions the minimum rise time of the instrument is available.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] Lewis and Wells, *Millimicrosecond Pulse Techniques* (McGraw-Hill Book Company, Inc., 1954), p. 208.

J8. Matrix Transformation of Multichannel Pulse-Height Analyzer Data. R. L. MATHER, *U. S. Naval Radiological Defense Laboratory.*—The data from an n-channel analyzer may be represented by a vector in n-space. If the desired experimental result is the distribution of photon sizes, for example, instead of pulse sizes, this n-vector may be transformed by an $n\times n$ matrix into another n-vector giving the distribution of photon sizes. The proper formulation of this matrix involves the detailed characteristics of the measuring instrument and an understanding of what the matrix does to the data and to its probable errors. The probable errors in the components of the transformed vector are no longer independent and incorporate ambiguities in the transformation process. The process is most easily understood by eliminating the quantitative aspects of the measurement and studying the instrument response and its transformations in an $(n-1)$ "quality" space. The problem becomes one of approximating the twisted curve of instrument response by a straight-sided curve with its apex points determining the reciprocal of the desired transforming matrix.

J9. Relaxation Times of Subcritical Reactor by Pulsed Neutron Techniques. E. C. CAMPBELL AND P. H. STELSON, *Oak Ridge National Laboratory.*—Relaxation time measurements of the decay of the fundamental mode of thermal neutrons leaking from subcritical $U^{235}-H_2O$ solutions of different sizes have been made by the use of a square-wave pulsed neutron source and multichannel time analyser. The dependence of relaxation time on reactor size gives information on its multiplicative properties permitting evaluation of characteristic nuclear parameters. Neutron bursts, generated by the modulated proton beam of the ORNL 5.5-Mev accelerator with Be target, were used to excite uranyl fluoride solution (53.0 g/liter U^{235}) in cylindrical containers. Neutrons leaking out between bursts were detected with a small $Li^6I(Eu)$ scintillation counter. Positions of source and detector were adjusted for minimum higher mode interference. Over the range of geometrical buckling from 0.072 to 0.54 cm^{-2} the measured half-life varied from 64.2 to 17.9 microseconds. Satisfactory agreement with theory is obtained if slowing down is described by a diffusion kernel with age equal to 25 cm^2.

J10. Spectrum Determination of Proposed Reactor Cores Using a Neutron Time-of-Flight Spectrometer. R. S. STONE AND R. E. SLOVACEK, *Knolls Atomic Power Laboratory.**—A method for the detailed experimental analysis of the thermal end of the spectra of a proposed reactor core is outlined. In this method a small fuel loaded matrix located in a reactor thermal column is used as a source for a neutron beam whose spectrum is representative of the core under consideration. The results of a detailed analysis on the correlation between the flux at the source point and the observed channel counting rates will be given. In particular, a channel weighting function and a consistent method of resolution specification will be outlined.

* Operated for the U. S. Atomic Energy Commission by the General Electric Company.

J11. Spheroidal Nucleus or Reactor. KIRK W. MCVOY* AND EUGENE GUTH, *ORNL.*—In a simplified treatment of neutron diffusion within a reactor, the neutron flux satisfies the wave equation, $(\nabla^2+k^2)\psi=0$. The boundary condition for a bare core without moderator is that $\psi=0$ at the surface, and in this

case the problem is identical with that of a Schroedinger particle in an infinite well. Eigenfunctions and eigenvalues for a spheroidal shape have conventionally been handled by perturbation theory[1] assuming small deformations. For nuclei, Mottelson and Nilsson[2] list eccentricities up to 0.31, in which case the validity of perturbation expansions is problematic; large deformations may also be of interest in reactor theory. Alternatively, the wave function is separable in spheroidal coordinates. This permits machine calculations of the eigenvalues, as undertaken by Hill and Wheeler (private communication). We have employed an analytical method for the prolate spheroid, using a development of spheroidal wave functions for small deformations and an asymptotic expansion for large deformations. The intermediate range can be bridged satisfactorily by interpolation. As an example we have treated the lowest eigenvalue (i.e., the critical size of the reactor) and the corresponding eigenfunction in some detail.

* Summer participant, Oak Ridge National Laboratory. Now at Brookhaven National Laboratory.
[1] S. A. Moszkowski, Phys. Rev. **99**, 803 (1955).
[2] B. R. Mottelson and S. G. Nilsson, Phys. Rev. **99**, 1615 (1955).

J12. Measurement of Electron Flux in a Radioactive Medium. R. D. BIRKHOFF, J. S. CHEKA, H. H. HUBBELL, R. M. JOHNSON, AND R. H. RITCHIE, *Oak Ridge National Laboratory.*—The spectral distribution of electron flux in a slab of P^{32} impregnated bakelite plastic has been measured. A channel cut into the plastic permits a small fraction of the electrons traversing a cavity in the material to escape into a solenoidal beta spectrometer for energy analysis. The experiment is analogous to the measurement of electromagnetic flux from a black-body cavity. Spectra are taken also with all radioactive material removed except that surrounding the channel, in order to evaluate the contribution from this source. When the latter is subtracted from the total, the resulting spectrum agrees well with the simplified Spencer-Fano-Attix[1,2] theory for the energy range from 0.35 to 1.7 Mev. Below this energy, agreement is less certain because of corrections which must be applied to the data due to the loss of transmission of the spectrometer.

[1] L. V. Spencer and U. Fano, Phys. Rev. **93**, 1172 (1954).
[2] L. V. Spencer and F. H. Attix, Radiation Research **3**, 239 (1955).

J13. Comparison of Ring and Disk Sources For Homogeneous Field Ring Focusing Spectrometers. DAVID B. BEARD, *University of California, Davis.*—Previous calculations[1–4] of the intensities and line profiles of finite sources for a homogeneous field ring focusing beta-ray spectrometer have neglected the dependence on φ, the angle the beta ray makes with the radial plane defined by the source point and the axis of the instrument. As pointed out by Jungerman and Beard,[5] beta rays emitted from points off the instrument axis are restrictive in this angle φ by momentum defining diaphragms which also, as is well known, limit the angle of the beta ray with the axis of the instrument. This restriction in φ diminishes the expected intensity from a finite source and alters the shape of the line profile. Using Hubert[4] diaphragms calculations have been made of the expected intensities and line shapes from disk and ring sources considering the φ dependence of off-axis rays, and the results will be presented.

[1] J. W. M. DuMond, Rev. Sci. Instr. **20**, 160 (1949).
[2] E. Persico, Rev. Sci. Instr. **20**, 191 (1949).
[3] E. Persico and C. Geoffrion, Rev. Sci. Instr. **21**, 945 (1950).
[4] P. Hubert, Ann. phys. **8**, 662 (1953).
[5] J. A. Jungerman and D. B. Beard, Rev. Sci. Instr. (to be published).

J14. Disposition and Effect of Necessary Supplementary Diaphragms in a Ring Source Ring Focus Beta-Ray Spectrometer. C. G. PATTEN, D. B. BEARD, J. A. JUNGERMAN, AND P. G. LICHTENSTEIN, *University of California, Davis.*—If a large diameter source is used in a homogeneous field ring focusing beta-ray spectrometer, the customary diaphragms which define the angle the beta rays make with the axis of the instrument are insufficient to obtain good momentum resolution. They must be supplemented by additional diaphragms which restrict the initial angle the beta ray makes with the plane containing the instrument axis and the source point. The disposition of these diaphragms and their effect on the line profile from a ring source will be discussed.

FRIDAY MORNING AT 9:00

Shoreham, Main Ballroom

(C. E. WIEGAND presiding)

K-Mesons, Hyperons, Antiprotons

JA1. Masses of *K*-Particles.* MARIAN WHITEHEAD, DONALD H. STORK, DONALD H. PERKINS, JAMES R. PETERSON, AND ROBERT W. BIRGE, *University of California, Berkeley.*—The measured ranges of 25 positive pions from the $K_{\tau 2}$ and 20 muons from the $K_{\mu 2}$ enable one to calculate the Q-values and therefore the masses with good accuracy using W. Barkas' new range-energy curves.[1] The statistical errors due to straggling are about 2 electron masses. These secondaries were measured in a large emulsion stack exposed to the K-beam at the Bevatron. In the same stack the primary masses of identified positive K's (100τ, 97 $K_{\mu 2}$, 55 $K_{\tau 2}$, 5 K_β, 10 $K_{\mu 3}$) have been measured with respect to protons by the momentum-range method. These values for the $K_{\mu 2}$, $K_{\tau 2}$, and τ all lie within 2 electron masses of the τ mass as determined from the Q of the τ decay: $966m_e$. The masses computed from the *secondary* ranges indicate that any cascade scheme must be consistent with a difference between the τ and θ masses that is less than 5 electron masses.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] W. Barkas, "Masses of K-Mesons from Ranges of Their Secondaries," UCRL 3298, February, 1956.

JA2. Masses of *K*-Mesons from Ranges of Their Secondaries.* WALTER H. BARKAS, HARRY H. HECKMAN, AND FRANCES M. SMITH, *University of California, Berkeley.*—Our recent measurements have established several high-velocity points relating meson ranges in emulsion and their momenta. The measured ranges agree with the curve of Barkas and Young to about 1%, but for determining momenta of K-particle secondaries a better relation is needed. With the cooperation of James Baker a digital computer has been used to calculate a new curve. A mean ionization potential of 323 ± 11 ev was

found by trial best to fit the measured points. Our τ-meson secondary ranges with the new curve lead to a Q-value of 75.08 ± 0.20 Mev. The τ mass is, therefore, $966.3\pm0.7\ m_e$; the accuracy now is limited chiefly by the uncertainty in the pion masses. Ranges of secondaries from $K_{\pi 2}$ and $K_{\mu 2}$ modes of decay have been measured by several groups. From averages of all known ranges (corrected for emulsion density) we find $K_{\pi 2}=962.6\pm1.6\ m_e$ and $K_{\mu 2}=963.4\pm2.1\ m_e$. Errors quoted are standard deviations arising from range straggling alone. The magnitude of the straggling is about as expected from theory. Systematic errors as follows remain: (a) errors in L-meson masses, (b) uncertainty as quoted in mean ionization potential, (c) radiative decay, (d) deficiencies in Bethe-Bloch stopping theory, (e) errors in correction for density effect.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

JA3. Hyperfragments from Negative K-Particle Captures and the Mass of a Negative K-Particle.* FRANCIS C. GILBERT, CHARLES E. VIOLET, AND R. STEPHEN WHITE, *University of California, Berkeley and Livermore.*—Among 125 negative K-particle captures in flight and at rest in emulsion five hyperfragments have been observed. The interactions took place in a 6-by-6-in. emulsion stack of 112 Ilford G.5 emulsions that was exposed in the K^--beam of the Berkeley Bevatron at a momentum of approximately 340 Mev/c. One hyperfragment has been identified as a ΛLi^7, which came out of a star caused by a K^--capture in carbon. The binding energy of the Λ hyperon in ΛLi^7 was found to be 2.3 ± 0.7 Mev. From the identification and measurement of the tracks of the capture reaction, the K^- was found to have a mass of 970.4 ± 5.0 electron masses. A second hyperfragment from the capture of a K^- in a light element has been identified as ΛHe^4 with a Λ binding energy of 1.5 ± 0.6 Mev. Three additional hyperfragment decays are now being analyzed and the results will be presented.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

JA4. π^0 Modes of Heavy-Meson and Hyperon Decay.* JOHN E. OSHER, BURTON J. MOYER, AND SHERWOOD I. PARKER, *University of California, Berkeley.*—Electromagnetic decay modes of heavy mesons and hyperons have been investigated by measuring the variation in counting rate of a well-collimated γ telescope, as the counter and its associated collimation were moved to observe regions near a Bevatron target. This technique was used at Bevatron energies of 6.0 to 6.2 Bev, and the decay events leading into π^0 mesons with subsequent decay to γ's were followed 5 cm upstream and 15 cm downstream from the target, with the on-target radiation more than 300 times as intense as from a region 5 cm downstream. The average $1/e$ distances were respectively 0.8 cm and 2.2 cm, with an apparent break 8 cm downstream into a longer decay distance. The complementary charged mode of decay was observed in a region more limited by collimation problems. Preliminary calculations of the lengthy kinematics show that the upstream decays, caused only by heavy-meson events, and the first section of downstream decays are consistent with a lifetime of 1.7×10^{-10} sec. This suggests the identification $\theta^0\rightarrow\pi^0+\pi^0$, with neutral and charged decay modes within an order of magnitude of each other, and requires the spin of the θ^0 to be even. The longer lived component downstream was consistent with $\Lambda^0\rightarrow\pi^0+N$.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

JA5. Composition of a Beam of Scattered K^+-Mesons.* A. M. SHAPIRO AND M. WIDGOFF, *Harvard University*, D. FOURNET, A. PEVSNER, D. RITSON, AND R. SCHLUTER, *MIT*, V. HENRI, *Northeastern University*, AND V. FITCH, *Princeton University.*—An experiment has been performed to determine the relative frequencies of occurrence in a scattered K^+-meson beam, of K-particles decaying in the various modes. According to the analysis of Dalitz and others, τ and $K\pi 2$ mesons differ in parity-spin properties. If this is so, it is reasonable to expect them to have different scattering cross sections, and therefore, the $\tau/K\pi 2$ ratio in a scattered beam of K^+-mesons should differ from that in an unscattered beam. To study the scattered mesons, a stack of Ilford G5 emulsions was exposed at the Cosmotron to a magnetically selected beam of K^+-particles emerging from an uranium target at 120° to the primary proton beam. By kinematics, it is very unlikely for K-particles to be produced directly at this angle in a nucleon-nucleon interaction, so the substantial flux of K-mesons seen in these plates must constitute a predominantly scattered beam. By along track scanning, a ratio of $\tau+\tau':K_L=17:215$ has been found. This is in agreement with the ratio found at forward angles by Harris and Orear (private communication), thus indicating that if two components are present in the beam, their scattering cross sections are similar, if not identical.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

JA6. Study of K-Mesons by Drop-Counting, Momentum, and Range.* J. BALLAM, G. K. LINDEBERG, AND C. G. MCGREW, *Princeton University.*—The momentum cloud-chamber part of the Princeton dual cloud-chamber apparatus now operated at Echo Lake, Colorado has been running under conditions suitable for drop-counting techniques. The presence of the multiplate chamber below has several advantages in this technique over the momentum chamber by itself, namely: (a) calibration of tracks of known stopped particles can be made independent of gas distortions in the momentum chamber; (b) any particle that enters the multiplate chamber after leaving the momentum chamber cannot be an electron; and (c) the interaction of identified K-particles can be observed. The momentum chamber is filled with a mixture of 90% He and 10% A and a vapor of water and ethyl alcohol. The expansion is delayed 5 msec after a coincidence from the counter telescope and the light delay is 110 msec. Using a 90-mm lens of f 22 and a demagnification of 8 gives droplet images of 25 microns and minimum ionization track widths of 125 microns on the film. This is achieved over an illuminated depth of 13 cm. Counting is done with the tracks divided into 160 micron cells. The analysis and correction for drop overlap and temperature gradient is done according to the method of Fretter *et al.*

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

JA7. Propane Bubble Chamber Study of the Interactions of 1.5-Bev π^- Mesons in Hydrogen. Part I. Experimental Technique.* M. CHRETIEN, J. LEITNER, N. SAMIOS, M. SCHWARTZ,† AND J. STEINBERGER, *Columbia University.*—The chamber is 6 in. in diameter and 4 in. deep, without magnetic field. The density of hydrogen is 0.08 g/cm³. The entering beam is collimated so that the energy resolution is $\pm1\%$. Approximately 30 000 pictures were obtained, each with $\sim15\pi^-$ tracks. Of these pictures, about 7000 have been scanned systematically for (a) two prong stars, (b) stopped mesons with associated V's. The separation of these events into the following classifications: (1) $\pi^-+P\rightarrow\pi^-+P$; (2) $\pi^-+P\rightarrow\Lambda^0+\theta^0$; (3) $\pi^-+P\rightarrow\Sigma^0+\theta^0$; (4) $\pi^-+P\rightarrow\Sigma^-+K^+$; (5) other events are made on the basis of angular correlation, coplanarity, and bubble density of the tracks. The range is in some cases also available. The method seems to be of sufficient accuracy, so that the number of ambiguous events are a small fraction of the total number.

* This research was supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† National Science Foundation predoctoral fellow.

JA8. Propane Bubble Chamber Study of the Interactions of 1.5-Bev π^- Mesons in Hydrogen. Part II. Results.* J. LEITNER, M. CHRETIEN, N. SAMIOS, M. SCHWARTZ,† AND J. STEINBERGER, *Columbia University.*—The reactions (1) $\pi^-+p\rightarrow\Lambda^0+\theta^0$, (2) $\pi^-+p\rightarrow\Sigma^-+K^+$, (3) $\pi^-+p\rightarrow\pi^-+p$ have been studied by means of a propane bubble chamber. Already observed are 16 cases of (1) and 7 cases of (2) where one or both secondaries decay. Angular distributions for the production and decay of the above strange particles will be presented. Data for the lifetime of the Σ^- will also be discussed. About 350 cases of reaction (3) have been measured and show a diffraction peak with a width of about 60°. In addition to the above, there are several events in which a θ^0 is seen which fits the reaction $\pi^-+p\rightarrow\Sigma^0+\theta^0$ as well as several in which a γ ray is observed in association with a Λ^0. These may serve as evidence for the existence of the Σ^0.

* This research was supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† National Science Foundation predoctoral fellow.

JA9. Anomalous *V*-Particles from the Cosmotron.* G. G. SLAUGHTER, M. M. BLOCK, AND E. M. HARTH, *Duke University.*—A beam of 1.9-Bev π^- mesons was incident upon a twenty atmosphere hydrogen-filled diffusion cloud chamber in a magnetic field. A total of 61 V^0-particles,[1] presumably produced in the stainless steel walls of the cloud chamber, were observed to decay in the gas. Six of the V^0-decays did not satisfy the kinematics of either the Λ^0 or the θ^0-decay scheme. In events 11 375 and 08 737 the V^0 undergoes β decay,[2] and event 12 647 also has a secondary which is most probably a negative electron. Event 12 944 is interpreted as a decay into a positive K-particle and a negative light meson. Event 00 354 suggests an alternate decay mode of the Λ^0. In event 95 638 both secondaries were of pion mass or lighter with a $Q(\pi-\pi)$ value of 45±3 Mev. In addition to the aforementioned events, one picture contained the decays of a negative V and a neutral V. The primary and secondary of the negative V were found to be coplanar with the line connecting the vertices of the two decays.

* Work supported jointly by the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Slaughter, Harth, and Block, Bull. Am. Phys. Soc. Ser. II, 1, No. 1, 64 (1956).
[2] Block, Harth, and Blevins, Phys. Rev. **100**, 959 (1955).

JA10. Further Results From the Study of V^0-Particles. ISHWAR C. GUPTA, ALLEN L. SNYDER, AND W. Y. CHANG, *Purdue University.*—Since the last Chicago Thanksgiving meeting we have accumulated altogether 254 V-events. Of these, 102 events have been analyzed according to the $\alpha-\epsilon$ ionization procedure with the following results: 52 have been classified as due to θ^0 particles, 31 as resulting from Λ^0 particles, 9 as "nonclassified" events, and 10 as anomalous cases. As a consequence, the decay times of θ^0 and Λ^0 particles are $[0.6(-0.1, +0.1)]\times10^{-10}$ sec and $[3.6(-0.5, +0.8)]\times10^{-10}$ sec, respectively. After weighing for the detection efficiency, the numbers of θ^0 and Λ^0 particles are 132±25 and 66±20, respectively, giving a ratio 2±1. Both θ^0 and Λ^0 decays are of the two-body type, as exhibited by the noncoplanarity angular distributions. Angular distributions, in the rest system, of the decay products show a statistically significant deviation from the isotropic distribution, which indicates that the spins of θ^0 and Λ^0 particles are greater than 1/2. As estimated from the amount of departure, the spin of the θ^0 particles is 1. The differential momentum distributions of the θ^0 and Λ^0 particles have been obtained which indicate difference in shape and momentum range for the two types of V^0-particles. The mean detection probability of our cloud chamber has also been studied as a function of the momentum of the V^0-particles.

JA11. Interaction of Antiprotons in Lead Glass.* JOHN M. BRABANT, BRUCE CORK, NAHMIN HORWITZ, BURTON J. MOYER, JOSEPH J. MURRAY, ROGER WALLACE, AND WILLIAM A. WENZEL. *University of California, Berkeley.*—A continuation of the studies previously reported[1] concerning the interaction of antiprotons in a lead glass Čerenkov counter, together with further investigation of the shower-containing properties of the counter and its calibration, has led to the following results: (1) The average energy released by an annihilation event in the form of secondary particles producing Čerenkov light contained in the glass is slightly over 0.45 Bev. (2) The maximum energy we have seen thus far in the form of such secondaries is 1.1 Bev (±20%). (3) These results are shown to be compatible with calculations based upon expected modes of annihilation and upon the containment factor for the counter. (4) Measurements of attenuation of antiprotons in flight, incidental to the pulse spectrum experiments, indicate a cross section about 1.7 times geometric for attenuation of 450-Mev antiprotons in copper, and strongly suggest an average absorption cross section in the lead glass even higher than this for kinetic energies between 200 Mev and 400 Mev.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] Brabant, Cork, Horwitz, Moyer, Murray, Wallace, and Wenzel, Phys. Rev. **101**, 498 (1956).

JA12. Antiproton Measurements in Emulsion.* HARRY H. HECKMAN, FRANCES M. SMITH, AND WALTER H. BARKAS, *Radiation Laboratory, Berkeley.*—We have used a stack of nuclear track emulsion to study the production and behavior of antiprotons obtained by use of the 6.2-Bev beam of the Bevatron. Magnetically analyzed negative particles of 700 Mev/c emitted from the target in the forward direction were observed. The ratio of pions to antiprotons found was $\approx3\pm1\times10^4$. The mass calculated from range and momentum for two particles for which both the range and momentum could be determined was $1.01\pm0.03\ M_p$. The error indicated is statistical; an uncertainty of ~2% existed in the absolute momentum. By track opacity and residual range the mean mass also was measured to be $1.01\pm0.03\ M_p$. Scanning was carried out by observing the grain density of tracks entering the emulsion stack. If the first four centimeters of track is eliminated from the calculations, the mean free path based on the tracks of five definitely established antiprotons, for which two interactions in flight were observed, is 18.2 cm. If two additional events which we believe (but cannot prove) to be antiprotons are included, the mean free path is 28.7 cm. Photomicrographs of annihilation stars will be shown and analyses of the stars made.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

JA13. Antiproton Measurements in Emulsions.* G. GOLDHABER, R. W. BIRGE, W. W. CHUPP, G. EKSPONG, S. GOLDHABER, J. E. LANNUTTI, D. H. PERKINN, D. H. STARK, AND L. VAN ROSSUN, *University of California, Berkeley.*—An exposure of a number of emulsion stacks has recently been made at the Berkeley Bevatron to 700 Mev/c momentum-selected negative particles.[1] The evaluation of these stacks has been undertaken by a cooperative effort of groups at Berkeley and Rome.[2] To date 13 antiproton stars, in addition to those in the previous abstract, have been found at Berkeley. Of these, 5 antiprotons come to rest in the stack and give annihilation stars. While 8 give annihilation stars in flight. In addition two large angle scatterings of antiprotons have been observed. The mean free path in emulsion corresponds to a cross section of about two times geometric, which is consistent with counter experiments.[3] The number of charged π mesons emitted from annihilation stars varies from 0 to 5.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] Chamberlin, Chupp, Goldhaber, Lofgren, Segrè, and Wiegand (to be published).
[2] Amaldi, Baroni, Castagnoli, Franginetti, and Manfrandini.
[3] Chamberlain, Keller, Segrè, Steiner, Wiegand, and Ypsylantis (private communication).

FRIDAY MORNING AT 9:00

Shoreham, West Ballroom

(H. W. NEWSON presiding)

Neutrons, II

K1. Differential Neutron Resonance Cross Sections of Be^9 and Na^{23}.* R. O. LANE AND J. E. MONAHAN, *Argonne National Laboratory.*—The differential scattering cross sections of Be^9 and Na^{23} have been measured as a function of neutron energy in the ranges 530 to 900 kev with approximately 8-kev resolution for Be^9, and from 200 to 850 kev with approximately 16-kev resolution for Na^{23}. The data are represented in terms of the coefficients, B_L, in the expansion

$$\sigma(\cos\theta) = \sum_{L=0}^{4} B_L P_L(\cos\theta)$$

of the differential cross section. By comparing the experimentally determined coefficients with those of Blatt and Biedenharn[1] it is possible to obtain values of the potential phase shifts. In order to qualitatively fit the Be^9 data it has been found necessary to assume these phase shifts to be spin dependent. A corresponding analysis of the sodium data has not been completed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] J. M. Blatt and L. C. Biedenharn, Revs. Modern Phys. **24**, 258 (1952).

K2. Total Neutron Cross Sections at 14 Mev.* JACK HAUGSNES, *Argonne National Laboratory and Northwestern University.*—The total nuclear cross sections of several elements have been measured using a fast coincidence technique. A narrow cone of 14-Mev neutrons is defined by counting only those neutrons in coincidence with a narrow cone (about 2×10^{-4} steradian) of 3.5-Mev alpha particles from the $D-T$ reaction. By measuring the transmission for two positions of the neutron detector, it is possible to subtract out the counts resulting from inscattered neutrons experimentally. Cross sections will be reported for Cd, Pd, Nd, Sm, Hf, and Ta.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

K3. Slow Neutron Resonances in Cd and W.* R. B. SCHWARTZ, V. E. PILCHER, AND R. M. SCHECTMAN,† *Brookhaven National Laboratory.*—Neutron transmission measurements have been made on separated cadmium and tungsten isotopes at a resolution of 0.7 μsec/m, using the Brookhaven fast chopper. Breit-Wigner parameters for cadmium resonances have been obtained up to 120 ev. The value of $\bar{\Gamma}_n^0/D$ determined from the first four levels in Cd^{113} is $(1.4\pm0.7)\times10^{-5}$, based on a Γ_γ of 113 mv the radiation width of the 0.2-ev level. Resonance parameters for levels in tungsten have been determined up to 250 volts, and isotopic identification has been made for levels up to 400 volts. An average Γ_γ based on the five lowest levels is 48 ± 6 mv. The $\bar{\Gamma}_n^0/D$ determined for the first 11 levels in W^{183} is $(3.4\pm1.0)\times10^{-4}$; $\bar{\Gamma}_n^0/D$ for the first four levels in W^{182} is $(2.0\pm1.0)\times10^{-4}$. The $\bar{\Gamma}_n^0/D$ for W^{183} is one of the largest so far observed, and it is planned to check this by measuring the average cross section in the kev region.

* Work performed under contract with U. S. Atomic Energy Commission.
† Summer student from Pennsylvania State University.

K4. Half-Lives and Capture Cross Sections of the Heavy Plutonium Isotopes. J. P. BUTLER AND T. A. EASTWOOD, *Atomic Energy of Canada, Ltd.*, AND T. L. COLLINS, M. E. JONES, F. M. ROURKE, AND R. P. SCHUMAN, *Knolls Atomic Power Laboratory.**—Two samples of *MTR* irradiated plutonium had the following compositions: sample "*B*," 0.83 $\pm0.02\%$ Pu^{238}, $1.67\pm0.03\%$ Pu^{239}, $26.1\pm0.3\%$ Pu^{240}, $15.7\pm0.3\%$ Pu^{241}, $55.7\pm0.4\%$ Pu^{242}, $0.01\pm0.005\%$ Pu^{244}; sample "*C*," $0.076\pm0.005\%$ Pu^{238}, $0.056\pm0.004\%$ Pu^{239}, $0.673\pm0.008\%$ Pu^{240}, $0.217\pm0.008\%$ Pu^{241}, $98.90\pm0.02\%$ Pu^{242}, $0.076\pm0.005\%$ Pu^{244}. Plutonium was determined chemically[1]; aliquots were taken, alpha counted and alpha analyzed. Specific activities of the 4.88-Mev. and 5.15-Mev groups correspond to half-lives of 6580 ± 130 years for Pu^{240} and $(3.79\pm0.07)\times10^5$ years for Pu^{242}.[2,3] Uranium daughters were separated from sample "*C*." From the small 14-hr U^{240} component of the decay, a half-life of $\sim8\times10^7$ years was calculated for Pu^{244}. Some plutonium "*C*" was irradiated in the *NRX* reactor; afterwards the plutonium was purified and americium daughters separated and counted to determine 2.08-day Am^{245} and its 10.6-hour Pu^{245} parent.[4] The pile capture cross section of Pu^{244} is 2.1 ± 0.4 barns.

* Operated for the U. S. Atomic Energy Commission by the General Electric Company.
[1] Work done by A. J. Frey, Atomic Energy of Canada Limited.
[2] Inghram, Hess, Fields, and Pyle, Phys. Rev. **83**, 1250 (1951).
[3] Butler, Lounsbury, and Merritt, Can. J. Phys. (to be published).
[4] Fields, Studier, Friedman, Diamond, Sjoblom, and Sellers, J. Inorganic and Nuclear Chem. **1**, 262 (1955).

K5. Neutron Cross-Section Measurements on Plutonium.* R. E. COTÉ, L. M. BOLLINGER, J. M. LEBLANC, AND G. E. THOMAS, *Argonne National Laboratory.*—The total and fission cross sections of plutonium have been studied from thermal energies to several hundred electron volts with the Argonne fast chopper. Some of the total cross-section data have been reported previously in the form of cross section *versus* energy curves.[1] The joint study has been carried out with the aim of obtaining all of the parameters for many of the low-energy resonances. The relative fission cross section was measured by simultaneously recording, in the 1024-channel time analyzer, the counts from a thin boron plate counter and the fissions from a gas scintillation fission counter. Resonances in the fission cross section were observed at 0.3, 7.8, 11.0, 11.9, 14.3, 24.7, 15.3, 17.6, 22.2, 42, 44.5, 50, and 53 ev. Values of $\sigma_0\Gamma_f$ for those believed to be single resonances will be presented. The statistical accuracy of these numbers is several percent. If a value of Γ_γ is assumed, values of all of the parameters for many of the resonances can be obtained from the measurements of total and fission cross sections. In order to obtain measured values of all parameters further total cross-section work is underway to measure Γ_γ.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Brookhaven National Laboratory Report BNL-325.

K6. Neutron Resonance Parameters of U^{234} and U^{236}.* V. E. PILCHER AND D. J. HUGHES, *Brookhaven National Laboratory*, AND J. A. HARVEY, *Oak Ridge National Laboratory.*—The neutron resonance structure of U^{234} and U^{236} has been studied with the Brookhaven fast chopper. Transmission measurements were made using highly enriched samples of these isotopes and the observed resonances were analyzed by the area method. A determination of Γ_γ for the 5.2-ev level in U^{234} by thick-thin analysis gives a value consistent with that found earlier in U^{238}. For the other resonances reported here it was possible to obtain only Γ_n with the available samples. A value of $\Gamma_\gamma=25\pm5$ mv was used throughout this work. For

U^{234}, $\Gamma_n^0/D = 1.2\times10^{-4}$ and the average level spacing D is 14 ev, based on 15 levels observed up to 210 ev. For U^{236}, $\Gamma_n^0/D = 1.3\times10^{-4}$ and D is 17.5 ev, based on 8 levels observed up to 140 ev. The observed average level spacing in these isotopes is smaller than that of U^{238}, as is to be expected from binding energy considerations. The resonance absorption integral is 710 b for U^{234} and 310 b for U^{235} as calculated from resonance parameters, including the effect of higher energy levels and the 1/v tail.

* Work performed under contract with U. S. Atomic Energy Commission.

K7. Transmission of a Flat-Plate Neutron Shutter. R. E. SLOVACEK, *Knolls Atomic Power Laboratory.**—In conjunction with the reactor spectrum investigations using the neutron time-of-flight spectrometer, it has been necessary to calculate the transmission probability of a flat-plate neutron shutter. The details of this calculation will be discussed. Experimental methods for checking the validity of this calculation will be outlined. The results obtained are in agreement with those of Mostovoi[1] but disagree with those of Egelstaff.[2]

* Operated for the U. S. Atomic Energy Commission by the General Electric Company.
[1] Mostovoi, Pevzner, and Tsitovich, "The mechanical neutron velocity selector," A/CONF.8/P/640, USSR, (July 5, 1955).
[2] P. A. Egelstaff, "A thermal neutron time of flight spectrometer," AERE-N/R-1131 (1953).

K8. Neutron Thermalization by a Heavy Crystalline Moderator. M. S. NELKIN AND D. B. MACMILLAN, *Knolls Atomic Power Laboratory.**—The energy distribution of neutrons thermalized in an infinite homogeneous medium containing a crystalline moderator and absorbing material has been investigated for a simplified model of the crystal. A Debye model of the phonon spectrum is assumed, and a formal expansion in powers of the ratio of neutron mass to moderator atom mass is used. This expansion is carried out only to first order in the inelastic scattering cross section, and interference effects are neglected. The resulting integral equation for the neutron spectrum is solved numerically on the IBM-650. For 1/v absorption the results are compared to those for a monatomic gas[1] at the same temperature using the same approximations in solving the integral equation. Comparison is also made to the solution of the differential equation for a heavy gaseous moderator.[2] It is found that the resulting neutron spectra are very insensitive to the choice of scattering model even when the absorption is so strong that the spectrum bears no resemblance to a Maxwellian distribution.

* Operated by the General Electric Company for the U. S. Atomic Energy Commission.
[1] E. P. Wigner and J. E. Wilkins, Jr., AECD-2275 (unpublished).
[2] J. E. Wilkins, Jr., CP-2481 (unpublished) or Hurwitz, Nelkin, and Habetler (to be published).

K9. Dynamics of Water by Neutron Spectrometry. B. N. BROCKHOUSE, *Chalk River Laboratories.*—Energy distributions of initially monoenergetic neutrons scattered by a thin specimen of water have been measured at a series of scattering angles and temperatures. The spectra consist of an "elastic" component which decreases with increasing angle of scattering and temperature in much the same way as the Debye-Waller factor for a solid, and an inelastic component which increases in energy spread and intensity with increasing angle of scattering and temperature. Under high resolution (10^{-3} ev) the "elastic" component is revealed as inelastic with an energy broadening ($\gtrsim 10^{-3}$ ev at room temperature) which appears to increase with increasing angle of scattering. Since 95% of the scattering from water is incoherent scattering by the protons, these experiments yield information on the displacements of the protons as a function of time. A preliminary intuitive analysis of the variation of intensity and width of the "elastic" component using Van Hove's approach suggests that the results to date can be explained by taking the rms proton position (Δr) to have the asymptotic form $(\Delta r)^2 = a^2 + b\Delta t$ where $a \cong 6.5\times10^{-9}$ cms and $b \sim 3\times10^{-5}$ cm^2/sec at room temperature. This result, leads to the conclusions (1) that motions of the protons around oxygen atoms without mass transport are not very important, and (2) that both large and small diffusive motions of water molecules probably occur.

K10. Neutron Studies with a Large Liquid Scintillator.* LESTER L. NEWKIRK, HENRY C. CATRON, MALCOLM H. MACGREGOR, AND CHARLES J. TAYLOR, *University of California, Livermore.*—A 40-in. liquid scintillator has been constructed and used as an efficient neutron detector. The scintillator solution is a toluene—terphenyl—alpha-NPO mixture loaded with cadmium propionate in the ratio of 0.003 cadmium atoms per hydrogen atom. Scintillation pulses are observed by 24 Dumont 5-in. photomultiplier tubes. The detection efficiency of the scintillator for fission neutrons has been investigated by examining spontaneous fission processes in Cf^{252} and Cm^{244}. Data for $\bar{\nu}$ and the spectrum of ν were obtained and compared with values obtained at Los Alamos.[1] This scintillator is now being used to study $(n,2n)$ events in light nuclei.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] Diven, Martin, Taschek, and Terrell, LADC-2023.

K11. A 1024-Channel Neutron Time-of-Flight Analyzer.* R. W. SCHUMANN, *Argonne National Laboratory* (introduced by L. M. Bollinger).—A simple data accumulating computer with a 1024-word, 16-digit magnetic core memory is used for data storage in time-of-flight measurements. Use of digital-computer techniques results in exceptional economy of vacuum tubes and permits automatic data readout both in digital form and as a precision pen recording of counts *versus* channel number. A CRT display of counts *versus* channel number is provided. Each of four groups of 256 counting channels may be independently located into essentially any time region to avoid wasting counting channels in regions of no interest. Channel widths are adjustable from 0.5 microsecond to essentially any higher value. There is a 16-microsecond dead time following each recorded count. The operator may elect to operate the instrument as two 512-channel systems for recording the events detected by two separate counters. A description of the general design techniques and a discussion of performance since installation will be given.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.

K12. Measurement of Nuclear Radii by Scattering of Kilovolt Neutrons.* D. J. HUGHES AND V. E. PILCHER, *Brookhaven National Laboratory.*—The potential scattering cross section, σ_p, for low-energy neutrons can be directly related to the nuclear radius, R. For a strongly absorbing nucleus with a sharp edge, $R = (\sigma_p/4\pi)^{\frac{1}{2}}$. Whereas the relationship of σ_p to R is direct, the experimental determination of σ_p is complicated by the presence of resonance structure in the cross section. In the present work σ_p is obtained from the average cross section in the region 1 to 5 kilovolts. The cross section averaged over many reasonances is measured and the resonance contribution is identified because of its rapid decrease by self-absorption with sample thickness. The potential scattering is obtained from a sample of moderate thickness by correcting for self-absorption and hardening, the corrections being sufficiently small that the measured cross section is constant over a considerable range of sample thickness. The values of σ_p obtained in this way for silver, thorium, and uranium are 6.2 ± 0.4, 12.2 ± 0.8, and 10.8 ± 0.5 b, which give r_0's of $(1.48\pm0.05,\ 1.60\pm0.05,$ and $1.50\pm0.04)\times10^{-13}$ cm in the formula $R = r_0 A^{\frac{1}{3}}$. These radii agree with those determined

with low-energy neutrons from the cross section between resonances, and are significantly larger than the electromagnetic radii and the nuclear-interaction radii for Bev neutrons.

* Work performed under contract with U. S. Atomic Energy Commission.

K13. Preliminary Studies with the 7.7-Meter Bent-Crystal Gamma-Ray Spectrometer.* DAVID ROSE AND BERNARD HAMERMESH, *Argonne National Laboratory.*—A gold foil 1-mil thick and 10×0.2 cm has been placed inside the reactor *CP*-5 at the focal volume of the 7.7-meter bent-crystal gamma-ray spectrometer. With the bent quartz crystal of dimensions 10×15×0.6 cm in place a study of the 411.8-kev line was carried out. The line was studied in both positive and negative first order. The 411.8-kev line has a full width at half-maximum of 13 sec of arc. This is approximately 0.15 milliangstroms and represents a resolution of 0.5%. The peak-to-valley ratio for the line is greater than 4 to 1. A preliminary measurement of the reflectivity of the quartz at 411.8 kev yields a value of 0.015. This value for a 6-mm crystal is to be compared with Lind's[1] value of 0.003 for a 1-mm crystal. A study of the neutron capture gamma rays from gold is being carried out.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] Lind, West, and J. DuMond, Phys. Rev. **77**, 475 (1950).

FRIDAY MORNING AT 9:30

NBS, East Building

(C. P. BEAN presiding)

Ferromagnetism and Ferroelectricity

KA1. A Model for the Square Hysteresis Loop.* JAMES D. CHILDRESS,† *Lincoln Laboratory.*—Goodenough[1] has shown that domains of reverse magnetization may be nucleated periodically at grain boundaries to reduce the surface pole distribution energy. If the pole distribution energy density is sufficiently large, ellipsoidal reverse domains exist at remanence.[2] Hence a periodic array of ellipsoidal reverse domains (at remanence) is taken as a model for the square minor hysteresis loop and the induction reversal process. For a field $|H| < |H_c|$ the reverse domains grow or shrink (dependent on the direction of the applied field) while maintaining constant eccentricity and thereby account for the reversible permeability at remanence in square loop materials.[2] For $H = H_\lambda$ in the demagnetizing direction, the domains elongate into cylinders; if $H_\lambda > H_w$, the critical field for irreversible cylindrical wall movement, the cylinders grow to reverse the net induction completely. The resultant hysteresis loop is square with $H_c \approx H_\lambda$. Various factors which affect the loop squareness and the time for induction reversal are discussed.

* The research in this document was supported jointly by the Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.
† Now at General Ceramics Corporation.
[1] J. B. Goodenough, Phys. Rev. **95**, 917 (1954).
[2] J. D. Childress, Proc. Conf. on Magnetism and Magnetic Materials (Am. Inst. Elec. Engrs.), 210 (October, 1955).

KA2. Field Dependence of Curie Temperatures. H. A. BROWN, *University of Miami.*—The Bethe-Peierls-Weiss method has been used to investigate the dependence of the Curie temperature on the applied field for both ferromagnetics and antiferromagnetics. For small applied fields ($\mu H \ll kT$), the result is that the ferromagnetic Curie temperature increases slowly with the field, whereas, for antiferromagnetics, there is no first-order change in the Curie temperature. The Curie temperature has been defined as in the zero-field case, as the temperature at which the consistency condition[1] has a nontrivial solution when the applied and internal fields are small.

[1] H. A. Brown and J. M. Luttinger, Phys. Rev. **100**, 685 (1955).

KA3. Relaxation Damping in Ferromagnetic Materials.* T. L. GILBERT, *Illinois Institute of Technology.*—The theory of magnetic after effect in metals was first developed, in its presently accepted form, by Néel.[1] A similar mechanism was suggested for ferrites by Wijn and van der Heide[2] and studied by Galt,[3] Clogston,[4] and others.[5] A consistent and general formulation of the theory will be presented, proceeding deductively from a model wherein particles (electrons or interstitial atoms) are distributed among potential wells, the relative depths of which are functions of the direction of the magnetization field. New energy balance relations useful for calculating experimentally observable results will be presented. The steady state motion of a domain wall will be treated as an example. The nonlinear dependence of the velocity on the reciprocal of the applied field and the nonrealizability of a steady state for long relaxation times will be discussed.

* Work supported by the Department of Defense.
[1] L. Néel, J. phys. radium **13**, 249 (1952).
[2] H. P. J. Wijn and H. van der Heide, Revs. Modern Phys. **25**, 98 (1953).
[3] J. K. Galt, Bell System Tech. J. **33**, 1023 (1954).
[4] A. M. Clogston, Bell System Tech. J. **34**, 739 (1955).
[5] Yager, Galt and Merritt, Phys. Rev. **49**, 1203 (1955).

KA4. Motion of Single Domain Walls in Manganese Ferrite. J. F. DILLON, JR., *Bell Telephone Laboratories.*—From a manganese ferrite single crystal,[1] specimens have been cut which are capable of supporting single domain walls. These cores are polygonal rings with each leg parallel to a [111] direction.[2] The legs have been proportioned in two ways; one favoring a moveable (110) wall, the other favoring a wall system perpendicular to (110). The basic experiment consists in applying rectangular current pulses to a winding, and observing the rate of change of flux as represented by the voltage in another winding. At low driving fields the output pulse starts with a nucleation period during which the wall is torn loose from the crystal surface. This is followed by a uniform wall velocity until the field is removed or the magnetization is completely switched. As the driving field is increased the nucleation time decreases rapidly, the wall velocity increases linearly with field. Such behavior, typical of the motion of a single domain wall, was observed below 200°K. At higher fields the pulse shapes indicate complex domain structure. The behavior of the wall motion constants in the temperature range below 200°K will be described.

[1] Grown by R. W. Kebler, Linde Air Products Company.
[2] J. K. Galt, Phys. Rev. **85**, 664 (1952); H. J. Williams and W. Shockley, Phys. Rev. **75**, 178 (1949).

KA5. Cation Distribution in Magnesium Nickel Ferrites. C. J. KRIESSMAN AND S. E. HARRISON, *Remington Rand Univac.*—Useful information about site energies and the degree of inversion in the ferrimagnetic spinels may be obtained by a study of the ionic distribution with changing composition.

In this particular investigation, the distribution of ions in the system $Mg_yNi_{1-y}Fe_2O_4$ is determined by observing the saturation magnetization as a function of quench temperature. From these data and the theoretical equations for the distribution two parameters related to the energy necessary to transport a Mg ion from a B site to an A site may be calculated. The evaluation of these parameters for different ferrites gives detailed information about the relative site energies for the various ions. An indication of the degree of inversion in the spinel structure may be obtained by comparing the experimentally determined maximum fractions of Mg ions on A sites with the values consistent with maximum disorder. In the magnesium-nickel ferrites the data is best explained by a very small fraction of nickel ions on A sites.

KA6. Magnetic Structures of the Manganous Sulfides. I.* N. ELLIOTT, L. M. CORLISS, AND J. M. HASTINGS, *Brookhaven National Laboratory.*—Manganous sulfide exists in three allotropic forms. In the α form, with the NaCl structure, the sulfur atoms have octahedral symmetry, and allow antiferromagnetic exchange between a Mn atom and its six second near neighbors. In the β forms of MnS, with the ZnS structures, the sulfur atoms have tetrahedral symmetry, and should allow antiferromagnetic exchange only between a Mn and its twelve nearest neighbors. High-temperature magnetic measurements on the manganous sulfides may be interpreted as indicating second near neighbor interaction in the α structure and nearest neighbor interaction in the β structures, provided one assumes the exchange integral is not much affected by the difference in bonding in the different forms.

* Research performed under the auspices of the U. S. Atomic Energy Commission.

KA7. Magnetic Structures of the Manganous Sulfides. II.* L. M. CORLISS, J. M. HASTINGS, AND N. ELLIOTT, *Brookhaven National Laboratory.*—The antiferromagnetic structures of the three allotropic forms of MnS have been determined by neutron diffraction. The rock salt form exhibits ordering of the second kind in agreement with earlier work.[1] The spin direction, however, is found to lie in the (111) sheets rather than along cube edges. In the zinc blende structure the manganese lattice is unaltered but the coordination of sulfur atoms is tetrahedral instead of octahedral. The antiferromagnetic arrangement here is the hitherto unobserved "improved ordering of the first kind" proposed by Anderson.[2] The spin direction is normal to the unique cell axis. The wurzite or hexagonal phase is characterized by an antiferromagnetic structure which can be derived from the Anderson model for the fcc lattice by stacking (111) sheets of the blende structure according to the scheme ABA . . . appropriate to hexagonal close packing. The number of antiparallel first and second neighbors is identical in the last two cases. The magnetic cell is orthohexagonal with $a=a_0\sqrt{3}$, $b=2a_0$, $c=c_0$. The spin direction is normal to the (011) plane.

* Research performed under the auspices of the U. S. Atomic Energy Commission.
[1] Shull, Strauser, and Wollan, Phys. Rev. **83**, 333 (1951).
[2] P. W. Anderson, Phys. Rev. **79**, 705 (1950).

KA8. Antiferromagnetic Structures of $FeCl_2$ and $CoCl_2$. M. K. WILKINSON AND J. W. CABLE, *Oak Ridge National Laboratory.*—Neutron diffraction investigations have been performed on polycrystalline samples of anhydrous $FeCl_2$ and $CoCl_2$ at various temperatures from 4.2°K to room temperature to determine the existence of magnetic ordering at low temperatures. These compounds crystallize in the pseudo-hexagonal (rhombohedral) layer structure characteristic of $CdCl_2$, and previous measurements of the magnetic susceptibility[1] and specific heat[2,3] have suggested antiferromagnetic transitions of 24°K for $FeCl_2$ and 25°K for $CoCl_2$. The neutron scattering data confirm these measurements by showing definite antiferromagnetic reflections at 4.2°K which disappear in the vicinity of the predicted Néel temperatures. For both compounds the magnetic reflections suggest an antiferromagnetic structure in which the moments are aligned parallel within each hexagonal layer with the moments of adjacent layers aligned antiparallel. However, although these compounds have crystal structures and magnetic ordering temperatures which are about the same, the direction of magnetic moment alignment in the proposed magnetic structure is different. For $FeCl_2$ the moments seem to be oriented parallel to the hexagonal axis, whereas the moment orientation in $CoCl_2$ is normal or nearly normal to that axis.

[1] Stair, Bitter, and Kaufmann, Phys. Rev. **58**, 977 (1940).
[2] O. Trapeznikowa and L. Schubnikow, Physik. Z. Sowjetunion **7**, 66 (1935).
[3] Trapeznikowa, Schubnikow, and Miljutin, Physik. Z. Sowjetunion **9**, 237 (1936).

KA9. Mechanism of Conductivity in Lithium Substituted Transition Metal Oxides. R. R. HEIKES AND W. D. JOHNSTON, *Westinghouse Research Laboratories.*—Electrical studies have been made on the systems $Li_xMn_{1-x}O$, $Li_xCo_{1-x}O$, $Li_xNi_{1-x}O$, and $Li_xCu_{1-x}O$. It has been found that (1) the activation energy (ΔE) for conduction increases abruptly at the antiferromagnetic Curie point, (2) as Li is added ΔE initially decreases and then levels off at $x\simeq 0.02$, (3) this initial decrease becomes progressively greater as one goes from MnO to CuO. It will be shown that these results can be understood on a model where ΔE has its origin in the local strain induced by the motion of the electron.

KA10. Magnetic Neutron Diffraction Study of $MnBr_2$ and $FeBr_2$. W. C. KOEHLER AND E. O. WOLLAN, *Oak Ridge National Laboratory.*—Neutron diffraction data have been obtained for $MnBr_2$ and $FeBr_2$ at temperatures down to 1.2°K. The antiferromagnetic structures of these compounds have been determined and in the case of $MnBr_2$ effects of an applied magnetic field on the moment alignment has also been studied. These compounds crystallize in an hexagonal CdI_2 type structure. The observed antiferromagnetic structures are of a layer type in which the moments are ferromagnetically aligned within each hexagonal layer and adjacent layers are antiferromagnetically aligned relative to each other. The magnetic cell thus has a c-axis which is twice that of the chemical cell. In the iron compound which has a Néel temperature of about 25°K, the moments are oriented parallel to the c-axis whereas in the manganous compound which has a sharp specific heat anomaly at 2.18°K (Néel temperature) the moments are oriented parallel or at least very nearly parallel to the hexagonal layers. In this compound pronounced magnetic field effects are observed in the intensity of the strong (001) reflection. The intensity is observed to increase to a saturation value for fields up to about 8000 oersteds for application along the scattering vector. Attempts to analyze the nature of these field effects are being made.

KA11. On the Theory of Ferroelectricity in $BaTiO_3$. S. TRIEBWASSER, *IBM Watson Laboratory.*—Since Devonshire's and Slater's work[1] on the theory of ferroelectricity in $BaTiO_3$ much additional data has become available, so that it is now possible to test the latter's results in greater detail. As a first step we have extended Slater's treatment to include sixth powers of displacements in the potential assumed. This addition yields a P^6 term in the free energy, as expected, but also leads to a linear variation with temperature of the coefficient of the P^4 term, of sign and order of magnitude agreeing with the observations of Drougard, Landauer, and Young.[2] Further, the internal fields have been recalculated allowing for the displacement polarizability of ions other than Ti. In addition corrections to the measured coefficients due to effects of strain and temperature expansion have been calculated.

The constants a, b_1, and b_2 in Slater's notation and the additional coefficient of the sixth-power terms have been calculated. The results depend on which atom is assumed to contribute the largest nonlinearity and asymmetry in the quartic terms in the potential.

[1] A. F. Devonshire, Phil. Mag. **40**, 1040 (1949); J. C. Slater, Phys. Rev. **78**, 748 (1950).
[2] Drougard, Landauer, and Young, Phys. Rev. **98**, 1010 (1955).

KA12. Polarization Reversal in the Barium Titanate Hysteresis Loop. R. LANDAUER, D. R. YOUNG, AND M. E. DROUGARD, *IBM, Poughkeepsie.*—In the presence of an opposing field the polarization of tetragonal $BaTiO_3$ reverses itself. Devonshire's phenomenological treatment shows that in a sufficiently large opposing field the original direction of polarization becomes unstable. The values of commonly observed coercive fields are much smaller than this, and the polarization actually reverses while the initial state is still metastable. The observed coercive fields and the shape of the audio frequency hysteresis loop can, however, be interpreted in terms of the $\exp(-a/E)$ rate measured by Merz in pulse experiments. Measurements of the small signal conductivity,[1] taken while traversing the hysteresis loop, are also explained in terms of the $\exp(-a/E)$ rate. The absence of an appreciable inductive component in the small signal conductivity measurements shows that variations in the applied field produce corresponding variations in the switching current with a time lag which is at most a few times 10^{-8} second, and possibly much less.

[1] Drougard, Funk, and Young, J. Appl. Phys. **25**, 1166 (1954).

KA13. Production of Very High Transient Magnetic Fields. M. A. LEVINE, H. FURTH,* AND R. WANIEK,* *Air Force Cambridge Research Center and Harvard University.*—Megaampere currents from a low-inductance capacitor bank have been constructed to produce multimegagauss magnetic fields in volumes of 30 cubic millimeters and pulse times of 20 microseconds. Some problems of current, force, and temperature distribution in the magnet will be discussed with a view to the limitations of the present method. The construction of the source and switch will be described.

* Partially supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

FRIDAY MORNING AT 9:30

Sheraton Park, Grand Ballroom

(A. V. ASTIN presiding)

Invited Papers

L1. Recent Work in Electron Microscopy by Reflection and in Electron Diffraction. GASTON DUPOUY, *Directeur, Centre National de la Recherche Scientifique, France.* (30 min.)
L2. Information Value of Photons. DENNIS GABOR, *Imperial College of London.* (30 min.)
L3. Electron Spectrometers. L. MARTON, *National Bureau of Standards.* (30 min.)
L4. Atomic Theory of Dielectrics. U. FANO, *National Bureau of Standards.* (30 min.)

FRIDAY MORNING AT 9:30

Sheraton Park, Continental Room

(W. W. BUECHNER presiding)

Transmutation, I, Including Scattering

M1. Thermonuclear Reactions in a Helium Gas. A. G. W. CAMERON, *Chalk River Laboratories.*—It is believed that the central regions of a star are compressed and heated following the conversion of hydrogen to helium. When the temperature reaches $\sim 10^8$ °K, the reactions $Be^8(\alpha,\gamma)C^{12}$, $C^{12}(\alpha,\gamma)O^{16}$, $O^{16}(\alpha,\gamma)Ne^{20}$, . . . take place. From stars with S, R, N, W, and He spectra it may be inferred that the carbon abundance greatly exceeds the oxygen abundance during much of the reaction period, and that the neon abundance becomes appreciable. It is also likely that these three abundances achieve roughly cosmic proportions when the helium is nearly exhausted. The reaction rates have been calculated as functions of nuclear parameters, and the abundance differential equations have been numerically integrated to find acceptable values of these parameters, corresponding to a variety of reasonable physical conditions. From the assumptions it follows that the 7.12-Mev level $(1-)$ in O^{16} has a reduced alpha particle width less than about 10% of the single particle limit, and that the 4.97-Mev level in Ne^{20} must be formable by combining alpha particles with O^{16}. The reduced alpha-particle width of this level has the following order of magnitude (as a fraction of the single particle limit), dependent on the spin; and parity assignment: $0+$, 0.004; $1-$, 0.008; $2+$, 0.04; $3-$, 0.4; $4+$, 7.

M2. Alpha Radioactivity of B^{12} and the Stellar Process $3He \rightarrow C^{12}$.* W. A. FOWLER, C. W. COOK, C. C. LAURITSEN, T. LAURITSEN, AND F. MOZER, *California Institute of Technology.*—It has been suggested that the fusion process, $3He^4 \rightarrow C^{12}$, plays an important role in the production of energy and in the synthesis of elements in red giant stars with helium rich cores at temperatures above 10^8 degrees. The rate of the process depends critically on whether the 7.65-Mev state in C^{12} has the correct spin, parity, and other properties to act as a stellar thermal resonance in $Be^8+He^4 \rightarrow (C^{12*}) \rightarrow C^{12}+\gamma$ ($Q=7.374$ Mev). Preliminary observations on the decay of

B^{12} indicate that low-energy α particles are emitted in approximately 1% of the disintegrations. The maximum energy of these α particles as determined by a strong focusing magnetic spectrometer is 195 kev and is consistent with the breakup of a state in C^{12} at 7.667 Mev into Be^8 and He^4. Thus the reverse process indicated above can occur through this state. A new determination of the decay energy of Be^8 yields a value of 91 kev. The energy equivalent of $C^{12*}-3He^4$, which occurs in the critical Maxwell-Boltzmann factor in the helium fusion process, is thus 384 kev. All numerical values are preliminary ones and must be assigned probable errors of the order of 10 kev.

* Supported by the joint program of the U. S. Atomic Energy Commission and the Office of Naval Research.

M3. Differential Cross Sections for High Energy Deuteron Photoeffect at 11.5°, 100°, and 175.5°.* C. A. TATRO, R. O. HAXBY, T. R. PALFREY, JR., AND R. M. WHALEY, *Purdue University.*—Measurements of the differential cross sections for disintegration of the deuteron by x-rays in the energy range 160 to 230 Mev, at center of mass angles of 11.5°, 100°, and 175.5° have been made with a magnet and counter-telescope system. Results at 11.5° and 175.5° were compared with extrapolated results from three recent studies[1-3] which did not extend to such small and large angles. Satisfactory agreement is found between the 11.5° measurements and the extrapolations. However, the 175.5° measurements show larger differential cross sections than would be indicated by the counter data,[1,2] but are in satisfactory agreement with Illinois' extrapolated results[3] in the energy region where the measurements overlap. Agreement with other investigators is found for the 100° measurements.

* Supported in part by the U. S. Atomic Energy Commission.
[1] D. R. Dixon, UCRL-2956, March 30, 1955 (unpublished).
[2] J. C. Keck, A. V. Tollestrup, Phys. Rev. **101**, 360 (1956).
[3] Whalin, Schriever, Hanson, Phys. Rev. **101**, 377 (1956).

M4. High-Energy Photoproton Emission at 9°.* F. W. MARKLEY AND T. R. PALFREY, JR., *Purdue University.*—The Z-dependence of the cross section for emission of high-energy photoprotons at 9° in the laboratory has been measured. Targets of Li, Be, C, Al, Cu, and Cd were bombarded by a 280-Mev bremsstrahlung spectrum from the Purdue electron synchrotron. A six-counter telescope placed behind a deflection magnet detected the emitted protons. One of these counters was a Čerenkov counter used to eliminate background pulses from soft showers. The protons were identified by pulse-height analysis of photographs of the five scintillation counter pulses. A partially completed analysis shows the cross section approximately proportional to Z.

* Supported in part by the U. S. Atomic Energy Commission.

M5. Energy Distributions of Protons from Photodisintegration. ALBERT L. WHETSTONE, PAUL F. YERGIN, AND J. HALPERN, *University of Pennsylvania.*—A proton energy spectrometer consisting of an NaI crystal with a photomultiplier and a 100-channel pulse-height analyzer has been used to observe photoprotons from F and Al, produced by 22- and 18-Mev bremsstrahlung. The spectrometer has a resolution of 3.5% in energy for the 5.3-Mev Po α particles. The background is zero for proton energies above 6 Mev, but pulses due to fast electrons in the NaI crystal give a background which increases rapidly with decreasing energy, at lower energies. Several thousand protons have been counted from each element at 22 Mev. The spectra show definite structural details, both at medium and high-proton energies. The resolution of details is limited by practical target thicknesses. All the measurements have been made at 90°. The apparatus is also well suited to measuring proton energy and angular distributions produced by the "direct" photoeffect in the heavy elements.

M6. Photo-Alpha Particles from Copper. M. ELAINE TOMS AND JOHN MCELHINNEY, *Naval Research Laboratory.*—Alpha particles produced by bombarding a 0.122-mil copper foil with 22-Mev bremsstrahlung x-rays have been observed in nuclear emulsions. A "sandwich" consisting of the copper foil lying between two 100-micron E.1 Ilford plates was placed in the x-ray beam. A grain gradation development process similar to that used by Millar and Cameron[1] permitted an exposure of 710 roentgens at the target. The arrangement permitted alpha particles at all angles to the beam to be observed. There seems to be some tendency for alpha particles having energies greater than 8.0 Mev to be more numerous at 90° to the beam. The bulk of the alpha particles had energies lying between 6 and 10 Mev in agreement with the energy distribution of Byerly and Stephens.[2] Of the 156 alpha particles observed, 13 had energies higher than 10 Mev. The yield was found to be $3.6\pm0.6\times10^4$ photo-alphas per mole-roentgen which is in good agreement with Byerly and Stephens' value of 4×10^4 obtained with 24 Mev bremsstrahlung.

[1] C. H. Millar and A. G. W. Cameron, Can. J. Phys. **31**, 723 (1953).
[2] P. R. Byerly, Jr. and W. E. Stephens, Phys. Rev. **83**, 54 (1951).

M7. Photoneutron Thresholds of Ag^{107}, Ag^{109}, Cu^{63}, and Cu^{65}. W. L. BENDEL, JOHN MCELHINNEY, AND R. A. TOBIN, *Naval Research Laboratory.*—Using the N.R.L. 22-Mev betatron and metallic samples, we have obtained the following photoneutron thresholds: 9.45 ± 0.05 Mev for Ag^{107}, 9.17 ± 0.06 Mev for Ag^{109}, 10.78 ± 0.05 Mev for Cu^{63}, and 9.94 ± 0.08 Mev for Cu^{65}. Published values[1] for these thresholds have shown some inconsistencies, and it was considered desirable to make the foregoing measurements. The thresholds of deuterium (heavy water), fluorine (Teflon), and oxygen (water) were determined in order to calibrate the betatron, using the isotopic masses of Wapstra.[2] The deuterium measurements utilized the neutrons produced; all other measurements employed the induced radioactivity. The oxygen activation curve shows a small "break" at 15.80 ± 0.07 Mev and a large "break" at 16.02 ± 0.05 Mev, in good agreement with the values of Penfold and Spicer.[3]

[1] D. M. Van Patter and W. Whaling, Revs. Modern Phys. **26**, 402 (1954).
[2] A. H. Wapstra, Physica **21**, 367 (1955).
[3] A. S. Penfold and B. M. Spicer, Phys. Rev. **100**, 1377 (1955).

M8. Elastic Scattering of 7.5-Mev Protons. N. S. WALL AND W. F. WALDORF, *Massachusetts Institute of Technology.*—The angular distributions relative to Rutherford scattering of protons elastically scattered from Ni, Cu, In, and Cd have been measured using 7.5-Mev protons from the M.I.T. Cyclotron. The Cu and Ni distributions are quite similar showing a forward maximum in the vicinity of 40°, a minimum at about 75°, and secondary maximum at about 110°. In addition to this structure Ni shows a second minimum in the vicinity of 151°. The cadmium and indium angular distributions both follow Rutherford scattering to about 70°. Cadmium then shows a slight maximum at about 80° whereas indium remains Rutherford to about 85°. Both elements then decrease at back angles to about 85% of Rutherford scattering near 130°. The indium ratio then rises at greater angles at a somewhat faster rate than does the Cd. The Cu and Ni results will be compared to data at other energies and the significance of these results relative to the complex potential well model of the nucleus will be discussed. In addition, a modification of the procedure, usually used in these experiments permitting one to measure the angular distributions with an accuracy independent of the angle of observation will be described.

M9. Elastic Scattering of 95 Mev Protons by Nuclei.* G. GERSTEIN, J. NIEDERER, AND K. STRAUCH, *Harvard University.*—Elastic differential cross sections have been measured with protons of 95 Mev in the angular region 3°–60° using C, Al, Cu, Ag, Ta, Pb, and Th targets. A range

telescope of 2-Mev energy resolution was used to attempt to separate elastic and inelastic events. An upper limit to the elastic differential cross section was obtained using all protons with energy greater than the beginning of the elastic peak. Due to the finite energy width of the incident beam a small fraction of such protons represented inelastic events. Correction for this effect will be described. Over-all angular resolution (including multiple scattering from the target) was 3° or better. The light elements show a broad region of destructive interference between nuclear and coulomb scattering. The width of this region decreases with increasing atomic number. Diffraction pattern minima are seen with all targets. The depth of the minima in general increases with increasing atomic number except that Ta and Th have less pronounced minima than Pb. This trend will be discussed. Assuming that the position of those diffraction minima unaffected by coulomb scattering is correctly given by the zeroes of $J_1(2kR\sin\theta/2)$, and that $R=r_0A^{\frac{1}{3}}$, a fairly consistent value of $r_0=1.23\times10^{-13}$ cm is obtained from Cu and heavier elements.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

M10. Polarization Measurements of Protons from (d,p) Reactions. A. C. JUVELAND AND W. JENTSCHKE, *University of Illinois.*—The targets were bombarded by 11.9-Mev deuterons, and the polarization of the liberated protons was measured by scattering them off He^4 near the $p^{\frac{1}{2}}$ resonance of Li^6. Assuming the most probable spin assignments, the sign of the polarization is opposite to that predicted by Newns.[1] For the ground state proton group from $C^{12}(d,p)C^{13}$, the sign and order of magnitude of the polarization agrees with that calculated by Cheston[2] for 3.29-Mev deuterons.

Reaction	Levels of C^{13} or Si^{29}	Proton Angle (cm)	Polarization[3]
$C^{12}(d,p)C^{13}$	Ground state	15.5±0.5°	−0.186±0.032
$C^{12}(d,p)C^{13}$	Ground state	18.5±0.5°	−0.151±0.040
$C^{12}(d,p)C^{13}$	Ground state	22.5±0.5°	−0.116±0.038
$C^{12}(d,p)C^{13}$	Ground state	35.5±0.5°	−0.051±0.057
$C^{12}(d,p)C^{13}$	Ground state	68.5±0.5°	−0.49 ±0.13
$Si^{28}(d,p)Si^{29}$	4.934 Mev	14.5±0.5°	+0.089±0.035
$Si^{28}(d,p)Si^{29}$	6.380 Mev	14.5±0.5°	−0.067±0.043

[1] H. C. Newns, Proc. Phys. Soc. (London) **A401**, 477 (1953).
[2] W. B. Cheston, Phys. Rev. **96**, 1590 (1954).
[3] The quantization axis is the same as that chosen by Cheston (reference 2).

M11. Excitation Functions for Nitrogen-Induced Nuclear Reactions in Sodium. M. L. HALBERT, T. H. HANDLEY, AND A. ZUCKER, *Oak Ridge National Laboratory.*—Thick NaBr targets were bombarded with nitrogen ions. The beam energy was varied from 26 Mev to 12 Mev with thin nickel absorbers. All reactions in the target were due to sodium because of the high Coulomb barrier in bromine. Excitation functions were measured for two reactions leading to radioactive residual nuclei, $Na^{23}(N^{14},\alpha p)P^{32}$ and $Na^{23}(N^{14},\alpha 2p)Si^{31}$. The yields for the first reaction were determined by counting the target after all short activities had decayed out and the 14.3 day P^{32} was unambiguously identified. Chemical separations were necessary to determine the yields of the 2.6-hour Si^{31}. The yield curves were differentiated to obtain cross sections as a function of incident energy for the two reactions. The P^{32} cross section is about 80 mb at 25.5 Mev, decreasing approximately exponentially to about 35 mb at 21.5 Mev and more rapidly below this energy. It is about 0.3 mb at 14.5 Mev. The Si^{31} cross section has a similar shape but is much smaller, ~4 mb at 25.5 Mev and ~0.4 mb at 19.5 Mev. The ratio of cross sections agrees approximately with the prediction of the statistical theory.

M12. Energy Distribution of Light Reaction Products from Bombardment of Beryllium by Nitrogen. JOHN L. NEED AND CHARLES D. GOODMAN, *Oak Ridge National Laboratory.*—A thin Be target was bombarded by 25-Mev N^{+++} ions from the ORNL 63-inch cyclotron. Energy distributions of the resultant protons, deuterons, tritons, and alpha particles were measured at zero degrees.[1] Preliminary measurements indicate that alpha particles of greater than 4 Mev, center of mass energy, constitute about one-third of the observed particles. Protons leaving Ne^{22} in the ground and first excited states were resolved, as were alpha particles leaving F^{19} in the two groups of levels near the ground state and 1.4 Mev. Alpha particles can be produced by two-step processes over most of the observed energy range. This complicates comparison with statistical theory. While two-step processes can occur for protons, the energetics are such that there is an 8-Mev region between the resolved discrete states and the region in which protons from these two-step processes can be produced.

[1] Charles D. Goodman and John L. Need, Bull. Am. Phys. Soc., Series II, **1**, No. 1, 41 (1956).

FRIDAY MORNING AT 9:30

Sheraton Park, Caribar-Mural Room

(E. FEENBERG presiding)

Theoretical Physics, III: Nuclear Theory

MA1. Nuclear Quadrupole Moments for Strong Coupling. N. R. STEENBERG, *University of Toronto.*—In the strongly coupled collective nuclear model of Bohr, oscillator type solutions are obtained by making an approximation for $T_{\text{vib}}(\partial/\partial\beta, \partial/\partial\gamma)$ the vibrational kinetic energy. This involves the neglect of a term $T'(\partial/\partial\beta, \partial/\partial\gamma)$ whose diagonal matrix elements are small. T' however couples higher oscillator states, $(n_\beta, n_\gamma>0)$ into the ground state which has a marked effect on the projection factor $P(x)$ which relates the observed quadrupole moment to the intrinsic deformation. The result is that β_0 as deduced from the measured quadrupole moment, or from the enhancement of transition rates, may, depending on the "strength" of the coupling, be as much as $2\frac{1}{2}$ times that deduced when this effect is neglected. The present result emerged from a detailed analysis of the simple Bohr picture for nucleons in a $j=5/2$ shell.

MA2. Effect of the Atomic Core on the Nuclear Quadrupole Coupling.* R. M. STERNHEIMER, *Brookhaven National Laboratory.*—The nuclear quadrupole moment induces a quadrupole moment in the electronic shells of the surrounding atom, which interacts with the valence electron and contributes to the quadrupole coupling[1] q. A calculation of this effect has been carried out for 11 atomic states. The terms of q due to the induced moment are of 3 types: (1) shielding terms which correspond to excitation of s-states of the core into d-states, and of p-states into excited f-states; (2) terms due to excitation of p-states into higher p-states, and $nd\rightarrow d$ terms, which

are generally antishielding; (3) exchange terms. For the B and Cl ground states, the ratio R of the induced effects (excluding exchange terms) to the direct interaction of the valence electron is positive (net shielding), whereas for the Na $3p$-, Rb $5p$-, and Cs $6p$-states, R is negative (antishielding) and of order -0.2. For the higher excited p-states of the alkalis, R tends toward a constant value which is of the same order as for the first excited states.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] R. M. Sternheimer, Phys. Rev. **84**, 244 (1951); **95**, 736 (1954).

MA3. Collective Rotations of Spheroidal Nuclei.* F. COESTER, *State University of Iowa.*—The Hamiltonian of a rotating spheroidal nucleus is derived in terms of intrinsic particle coordinates and collective angles of rotation by an appropriate coordinate transformation from an ordinary many particle Hamiltonian. This transformation and the resulting moment of inertia of the collective rotations depends on a parameter ζ, $0 \leq \zeta \leq 1$, which can be determined if the intrinsic particle wave function is known. For independent particles in a harmonic oscillator well the moment of inertia is very nearly that of a rigid nucleus in agreement with the results obtained from the Inglis model.[1,2] For other values of ζ smaller momenta of inertia are obtained. The range is sufficient to fit the observed values.

* Supported in part by the U. S. Atomic Energy Commission.
[1] D. R. Inglis, Phys. Rev. **96**, 1059 (1954); **97**, 701 (1955).
[2] A. Bohr and B. Mottelson, Dan Mat. fys. Medd., No. 1 (1955).

MA4. On the Ground State Properties of Spheroidal Nuclei. K. GOTTFRIED,* *Harvard University.*—We have computed the wave functions and energy levels for independent particle motion in a spheroidal potential of square-well shape; spin-orbit effects are included.[1] Within the framework of the Bohr-Mottelson model one may use the above information to compute the magnetic moment μ, ground-state spin I_0, and decoupling factor[2] a. For $150 < A < 190$, seventeen nuclei have known I_0, fourteen of which are in complete agreement with our scheme. For two nuclei (Lu^{175},Gd^{155}), one must resort to a slight reordering of levels, while W^{183} cannot be accounted for. The theoretical value of μ agrees with μ_{obs} for Eu^{151}, Tm^{169}, $Re^{185,187}$, $Yb^{171,173}$, and Os^{189}, as does a for Tm^{169}.[1] The only serious disagreement between μ_{theo} and μ_{obs} occurs for Lu^{175}, Gd^{155}, and Eu^{153}. On the other hand, the great difference between μ for $Eu^{151,153}$ is reproduced, a fact which the shell model could not explain. The success of the spin assignments indicates that our scheme must be essentially correct for the strongly deformed nuclei whose odd particle lies in the 50–82 shell or the lower part of the 82–126 shell.

* Junior Fellow, Society of Fellows.
[1] See also S. G. Nilsson, Dan. Mat. Fys. Medd. **29**, No. 16 (1955); S. G. Nilsson and B. R. Mottelson, Z. Physik **141**, 217 (1955); Phys. Rev. **99**, 1615 (1955).
[2] K. Siegbahn, *Beta- and Gamma-Ray Spectroscopy* (North-Holland Publishing Company, Amsterdam, 1955), p. 474.

MA5. Inelastic Scattering of Nucleons by Nuclei and the Intermediate Coupling Shell Model.* M. K. BANERJEE, C. A. LEVINSON, AND C. H. ALBRIGHT, *Princeton University,* AND W. TOBOCMAN, *Institute for Advanced Study.*—Many authors have shown that the intermediate coupling shell model gives a good description of excited and ground states of light nuclei. The wave functions arising from this model can therefore be expected to provide a good description of the targets involved in inelastic scattering. In particular, the influence of exchange scattering can be more accurately calculated as well as effects coming from the coupling of the particles in the target. Selection rules resulting from this approach will be discussed. Expressions for the cross sections for exciting various states in Li^6 and N^{14} will be given. In particular the low cross section for exciting the first spin zero state in Li^6 by 19-Mev protons[1] will be explained and the connection between such processes and β-decay matrix elements will be shown.

* Supported in part by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
[1] R. Sherr and W. F. Hornyak, Bull. Am. Phys. Soc., Series II, **1**, No. 4, 197 (1956).

MA6. Inelastic Scattering of 19 Mev Protons on Li^6-Distorted Wave and Surface Interaction Calculations.* C. A. LEVINSON, M. K. BANERJEE, AND C. H. ALBRIGHT, *Princeton University,* AND W. TOBOCMAN, *Institute for Advanced Study.*—The method of distorted waves as described by Mott and Massey[1] has been applied to the problem of inelastic nuclear scattering. In the case of Li^6 the elastic scattering was first analyzed in order to define the distorted waves. Real square wells were fitted to the s-, p-, and d-phase shifts, and the target was described by an intermediate shell model wave function. The results and their dependence on the extension of the nucleus will be given. An alternate approach quite similar to some of the stripping calculations of Tobocman and Kalos[2] using waves distorted by absorbing various orbital angular momenta was tried. The theoretical predictions of this model will be compared with those of the first model and the experiments of Sherr and Hornyak.[3]

* Supported in part by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
[1] *The Theory of Atomic Collisions* (Oxford University Press, New York, 1949), p. 144.
[2] W. Tobocman and M. H. Kalos, Phys. Rev. **97**, 132 (1955).
[3] R. Sherr and W. F. Hornyak, Bull. Am. Phys. Soc., Series II, **1**, No. 4, 197 (1956).

MA7. Neutron Cross Sections from Optical Models with Absorption near the Surface. H. J. AMSTER AND L. M. CULPEPPER, *Westinghouse Bettis Plant,* AND W. S. EMMERICH, *Westinghouse Research Laboratories.*—It has been shown analytically that a complex potential with the imaginary part concentrated to a layer beneath the surface improves the results of the complex square well in reproducing the experimental strength function Γ_n^0/D and the scattering length at zero energy. These results do not uniquely determine the distribution of absorption, and an attempt is being made to locate a particular form that will continue to exhibit improvements at finite energies. For this purpose, the NORC computer has been coded to calculate exactly cross sections from arbitrary potentials. The method of analysis is to seek the general shape of the potential by comparing total and compound nucleus formation cross sections for all elements at successively increasing energies. The details in the shape of the potential are to be investigated by a subsequent comparison with the angular distributions.

MA8. Calculation of Neutron Cross Sections by Use of the Optical Model.* E. W. SALMI, J. R. BEYSTER, AND M. WALT, *Los Alamos Scientific Laboratory.*—The optical model of the nucleus proposed by Feshbach, Porter, and Weisskopf,[1] modified to include a spatial dependence suggested by Woods and Saxon,[2] has been used for calculation of neutron cross sections. The potential, $V(r) = -(V+iW)/(1+\exp[(r-R_0)a^{-1}])$, contains four parameters which were varied independently to obtain agreement with experimental data at 2.5-, 4.1-, 7-, and 14-Mev neutron energy. Comparison is made between calculated and experimental values of the total cross section, the differential elastic scattering cross section, the inelastic collision cross section, and the derivative with respect to energy of the total cross section. Using the above potential, it is possible to obtain cross sections for compound nucleus formation which are at least as large as the experimental inelastic collision cross sections, a requirement which cannot be satisfied using a square-well radial dependence. Values of the parameters which fit the experimental data will be discussed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Feshbach, Porter, and Weisskopf, Phys. Rev. **96**, 448 (1954).
[2] Woods and Saxon, Phys. Rev. **95**, 577 (1954).

MA9. Compound Elastic Scattering of Neutrons.* W. S. EMMERICH AND R. M. SINCLAIR, *Westinghouse Research Laboratories.*—The complex potential model for neutron scattering predicts a division of the elastic scattering cross section into shape and compound scattering when averaged over compound nucleus resonances.[1] If the differential cross sections of the model are expanded in series of Legendre polynomials with coefficients σ_n, the odd terms vanish for compound elastic scattering. This holds in particular for σ_1 which is then due only to shape scattering. σ_0 has contributions from both shape and compound scattering. Graphs will be presented for $\bar{\mu}=\sigma_1/\sigma_0$ as a function of neutron energy. Experimentally, σ_0 and σ_1 can be obtained from transport cross sections or angular distributions.[2] Two theoretical limits will be shown: (1) for shape scattering only, and (2) for shape plus maximum compound scattering. The experiments indicate a gradual shift from limit (2) to limit (1) as the neutron energy increases and inelastic scattering becomes the predominant mode of decay of the compound nucleus. These results verify the prediction made by the model.

* Supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Feshbach, Porter, and Weisskopf, Phys. Rev. **96**, 448 (1954).
[2] Barschall, Manley, and Weisskopf, Phys. Rev. **72**, 875 (1947); M. Walt and H. H. Barschall, Phys. Rev. **93**, 1062 (1954); M. Walt and J. R. Beyster, Phys. Rev. **98**, 677 (1955); Langsdorf, Cross, and Walt (private communications).

MA10. Effective Range Theory in Nuclear Reactions.* C. E. PORTER, *Brookhaven National Laboratory,* AND H. FESHBACH, *MIT.*—The complex scattering length and the complex effective range provide, in principle, convenient, model-independent quantities for analyzing the energy dependence of energy-averaged, low-energy neutron cross sections. Numerical calculations of the effective range for a complex square well show a marked variation with nuclear size which is somewhat similar to that of the complex scattering length.

* This work was supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission.

MA11. Experimental Evidence on the Vector Interaction in β Decay.* J. B. GERHART AND R. SHERR, *Princeton University.*—Experimental data show that both Fermi and Gamow-Teller interactions occur in β decay with the scalar and tensor interactions predominating. The question of Fierz interference between axial vector and tensor interactions has been investigated extensively; Sherr and Miller[1] in their work on Na^{22} K-capture found $g_A/g_T <$several percent. Excepting rough limits from Kurie plots and neutrino correlations, the corresponding ratio for vector and scalar interactions, g_v/g_s, is unknown. For allowed decays involving only Fermi interactions $(ft|\int 1|^2)^{-1}=g_s^2+g_v^2-2\gamma\langle\epsilon^{-1}\rangle g_v g_s(\langle\epsilon^{-1}\rangle$ is the reciprocal electron energy in units of mc^2 averaged over the spectrum). Thus g_v/g_s can be determined from the energy dependence of $ft|\int 1|^2$. With published data for the O^{14}, Al^{26}, and Cl^{34} positron decays such an analysis gives $g_v/g_s=0.16 \pm 0.09$. If, instead of the O^{14} positron end point, Butler's tentative value[2] for the $C^{12}(He^3,n)O^{14}$ threshold is used, one obtains $g_v/g_s=-0.1\pm 0.2$. The values of $ft|\int 1|^2$ used are subject to small corrections for the finite de Broglie electron wavelength and failure of charge independence for nuclear forces.

* Supported in part by the U. S. Atomic Energy Commission and The Higgins Scientific Trust Fund.
[1] R. Sherr and R. H. Miller, Phys. Rev. **93**, 1076 (1954).
[2] J. W. Butler, Bull. Am. Phys. Soc. Series II, **1**, No. 2, 94 (1956).

MA12. First-Order Coulomb Corrections to Inner Bremsstrahlung in Beta Decay. G. FORD AND R. R. LEWIS, *University of Notre Dame.*—Recent experiments[1] on the photon spectrum accompanying beta decay in P^{32} and S^{35} have, for the first time, shown significant deviations from the predictions of the Knipp-Uhlenbeck-Bloch[2] theory. Using third-order perturbation theory, we have calculated the Coulomb corrections to the inner bremsstrahlung spectrum accompanying allowed beta decay. The result of this calculation has a simple interpretation in terms of the Sommerfeld correction factor. Numerical calculations based on this result have been carried out for P^{32} and S^{35}. The general result is that the first-order Coulomb corrections to the photon spectrum per beta decay are too small to explain the experimental deviations. A possible explanation will be presented.

[1] K. Liden and N. Starfelt, Phys. Rev. **97**, 419 (1955); N. Starfelt and N. L. Svantesson, Phys. Rev. **97**, 708 (1955).
[2] J. Knipp and G. E. Uhlenbeck, Physica **3**, 425 (1936); F. Bloch, Phys. Rev. **50**, 272 (1936).

FRIDAY AFTERNOON AT 2:00

NBS, Materials Testing

(C. C. LAURITSEN presiding)

Transmutation and Nuclear Energy Levels, II

N1. Proton Yields and Angular Distributions from the $Be^9(He^3,p)B^{11}$ Reaction. E. ALMQVIST, D. A. BROMLEY, H. E. GOVE, A. E. LITHERLAND, AND E. B. PAUL,* *Chalk River Laboratories.*—The Chalk River electrostatic generator has been equipped with a gas recovery system to permit the acceleration of He^3 with very low gas loss. The yields of protons in the reaction $Be^9(He^3,p)B^{11}$ to the first six states of B^{11} all show an increase with energy up to 1.8 Mev and then remain constant up to 2.7 Mev. The angular distributions are strongly anisotropic, in agreement with those observed by Holmgren, Bullock, and Kunz[1] at 2 Mev, and do not vary rapidly with energy. No evidence was found for any resonances in the yield between 1- and 2.7-Mev bombarding energy.

* Now at Atomic Energy Research Establishment, Harwell.
[1] Holmgren, Bullock, and Kunz, Phys. Rev. **100**, 436 (1955).

N2. Proton Yields and Angular Distributions from the $C^{12}(He^3,p)N^{14}$ Reaction. D. A. BROMLEY H. E. GOVE, A. E. LITHERLAND, E. B. PAUL,* AND E. ALMQVIST, *Chalk River Laboratories.*—The yield of protons corresponding to formation of N^{14} in its ground and first two excited states has been measured as a function of He^3 bombarding energy in the range 1.0 to 2.5 Mev using a carbon target of about 20 $\mu g/cm^2$. Resonances are observed at 1.18, 1.75, and 2.3 Mev. The 1.18-Mev resonance corresponds to the 13.09-Mev state previously observed in O^{15}.[1] The angular distribution of each of the three proton groups has been studied at bombarding energies of 1.18, 1.50, 1.75, 2.00, 2.25, 2.35, and 2.50 Mev. These angular distributions have also been measured at 2.00 Mev by Johnston and Holmgren.[2] These distributions change rapidly with energy, indicating strong interference effects. The distribu-

tion corresponding to the $1+$, $T=0$ ground and 3.95-Mev states are quite different.

* Now at Atomic Energy Research Establishment, Harwell.
[1] Blaser, Marmier, and Sempert, Helv. Phys. Acta **25**, 442 (1952).
[2] R. Johnston and H. D. Holmgren, Bull. Am. Phys. Soc. Series II, **1**, No. 1, 21 (1956).

N3. Gamma Rays from the $C^{12}(He^3,p\gamma)N^{14}$ Reaction. H. E. GOVE, A. E. LITHERLAND, E. ALMQVIST, AND D. A. BROMLEY, *Chalk River Laboratories.*—Low-lying excited states of N^{14} have been studied by observing the gamma rays emitted in the reaction $C^{12}(He^3,p\gamma)N^{14}$. The He^3 bombarding energy was about 1.4 Mev. The direct spectrum showed gamma rays of approximately 4.91, 2.31, and 1.64 Mev. The spectrometer comprised a 5-in. diameter by 4-in. long NaI(Tl) crystal and associated electronics. To study these gamma rays in more detail, coincidences between the proton groups, measured in a CSI crystal, and the gamma rays were measured. The spectrum in coincidence with the proton group feeding the 2.31-Mev level in N^{14} showed only a gamma ray of that energy, while that in coincidence with the proton group feeding the 3.95-Mev level showed gamma rays of 1.64 and 2.31 Mev of equal intensity and a very weak gamma ray of 3.95 Mev. Preliminary measurements of the branching ratio for the 3.95-Mev level indicate that $5\pm2\%$ of the transitions proceed directly to the ground state. This is consistent with recent measurements of Hind *et al.*,[1] who find $5\pm5\%$. A small ($\sim1\%$) branching ratio for this state has been predicted by Elliot.[1]

[1] J. P. Elliot (private communication); TPP-6, Atomic Energy Research Establishment, Harwell.

N4. Angular Distributions and Angular Correlations in $Be^9(d,p)Be^{10}$, $B^{10}(d,p)B^{11}$, and $Mg^{24}(d,p)Mg^{25}$.† S. A. COX AND R. M. WILLIAMSON, *Duke University.*—Angular distribution and angular correlation measurements have been made in $Be^9(d,p)Be^{10}$, $B^{10}(d,p)B^{11}$,[1] and $Mg^{24}(d,p)Mg^{25}$[2] at deuteron bombarding energies of 2.5 Mev, 3.0 Mev, 3.5 Mev, and 4.0 Mev. The proton groups investigated were the ones which left Be^{10}, B^{11}, and Mg^{25} in the 3.37-Mev, 6.76-Mev and 6.81-Mev, and 3.40-Mev excited states, respectively. The investigation was carried out to determine whether or not the shape of the angular distribution was a criterion for the validity of the angular correlation following the stripping process. The experimental correlations showed better agreement with the theoretically expected ones when the distributions indicated that stripping was the dominant process than when they did not indicate that stripping was the dominant process. However, comparison between the experimental and theoretical correlations was made difficult by the possibility of mixing of the various factors involved, and by the possibility of proton polarization.

† This work was supported by the U. S. Atomic Energy Commission.
[1] S. A. Cox and R. M. Williamson, Phys. Rev. **99**, 631(A) (1955).
[2] R. M. Williamson and S. A. Cox, Phys. Rev. **99**, 644(A) (1955).

N5. Angular Distributions of Protons from $Be^9(He^3,p)B^{11}$ at 4.5 Mev. E. A. WOLICKI, E. H. GEER, H. D. HOLMGREN, AND R. L. JOHNSTON, *Naval Research Laboratory.*—The angular distributions of the two most energetic proton groups resulting from the bombardment of Be^9 by He^3 particles at 2 Mev have been previously investigated.[1] Since it is expected that the effects of Coulomb interactions will be less important at high bombarding energies, this work has been repeated at 4.5 Mev. The Naval Research Laboratory 5-Mv Van de Graaff generator was used to accelerate the He^3 particles, and the protons were recorded in 200-micron Ilford C-2 emulsions. Slits in front of each emulsion subtended an angle of 0.12 degree at the target, which had been evaporated onto a 10-microinch nickel backing. Both angular distributions are peaked in the forward direction. The ground-state proton yield shows minima at about 65 and 120 degrees in the center of mass, and a maximum close to 100 degrees. The first excited state protons are peaked near 60 and 140 degrees, and have minima at approximately 30 and 100 degrees.

[1] Holmgren, Bullock, and Kunz, Phys. Rev. **100**, 436 (1955).

N6. The (d,p) and (d,α) Reactions in B^{10}.* GUSTAV WEBER† AND JERRY B. MARION,‡ *California Institute of Technology.*—The protons and α particles from the deuteron bombardment of B^{10} have been studied as a function of angle over the range of deuteron energy from 0.9 to 3.0 Mev. Excitation curves were obtained for the proton groups leaving B^{11} in the ground state and in the first three excited states. The ground-state group exhibited several weak resonances and a broad maximum near 2.5 Mev. The other three proton groups showed much smaller energy variations. The proton angular distributions do not appear to indicate strong stripping effects at these bombarding energies. Excitation curves were obtained for the ground-state α particles at 45°, 90°, and 135°. The observed asymmetries shift from forward to backward as the bombarding energy is increased, such that the cross section is approximately isotropic when averaged over the energy interval studied, in accord with the statistical model prediction.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† International Cooperation Administration Research Fellow.
‡ National Science Foundation Postdoctoral Fellow.

N7. The $B^{10}(n,t2\alpha)$ and $B^{10}(n,dn2\alpha)$ Reactions for 6- to 20-Mev Neutrons.* GLENN M. FRYE, JR., AND JUANITA H. GAMMEL, *Los Alamos Scientific Laboratory.*—Nuclear emulsions, loaded with B^{10}, were exposed to seven discrete neutron energies in the range 6 to 20 Mev. The three-prong triton and deuteron stars were identified by momentum and energy balance. The cross sections are as follows (for the triton and deuteron events, respectively): 19.5 Mev, 60 ± 12 and 140 ± 23 mb; 18.2 Mev, 81 ± 16 and 126 ± 20 mb; 16.1 Mev, 84 ± 16 and 100 ± 17 mb; 14.1 Mev, 102 ± 17 and 128 ± 19 mb; 12.2 Mev, 96 ± 21 and 69 ± 15 mb; and at the two lowest energies where only the triton reaction is seen; 7.7 Mev, 131 ± 23 mb; and 5.6 Mev, 239 ± 40 mb. The triton reaction proceeds partially through the 4.61-Mev state in Li^7 and partially as a direct three-body breakup. No evidence is seen for the formation of Be^8 in either the ground state or excited to the 2.9-Mev level. In the deuteron reaction the following intermediate nuclei are formed: Be^9, 2.43-Mev state; Be^8, ground state and possibly the 2.9-Mev level; Li^7, 10.8- and 12.4-Mev levels; and Li^6, 2.19-Mev level. Four examples of the $N^{14}(n,t3\alpha)$ reaction were found.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

N8. Search for Level in C^{12} Predicted by the Alpha-Particle Model. C. D. MOAK AND A. GALONSKY, *Oak Ridge National Laboratory.*—Recent theoretical work being reported at this meeting indicates that if C^{12} can be described by an α-particle model, then C^{12} will have a 3^- level at 5.54 Mev.[1] The $B^{10}(He^3,p)C^{12}$ reaction has been studied in a search for the predicted level. Some work has been done on this reaction by Bigham, Allen, and Almqvist.[2] In this work the proton groups were observed in a CsI crystal charged-particle spectrometer; a bombarding energy of 1.25 Mev was used. In the region between the 4.43-Mev and the 7.65-Mev levels of C^{12} one group of protons, attributable to B^{11} contamination in the target, was found. This group was rather weak but it could have obscured a proton group corresponding to a level in C^{12} if that level were near 6.4 Mev. The negative result given by this experiment could, of course, be due to the operation of some selection rule which might suppress transitions to the level in question; thus these results do not rule out the possibility that the level might appear in some other reaction leading to C^{12}.

[1] A. E. Glassgold and A. Galonsky, Bull. Am. Phys. Soc. Series II, **1**, No. 4, 180 (1956).
[2] Bigham, Allen, and Almqvist, Phys. Rev. **99**, 631(A) (1955).

N9. Angular Distribution of 15-Mev Gamma Rays Scattered from C^{12}.* J. E. Leiss and J. M. Wyckoff, *National Bureau of Standards.*—Fuller, Hayward, and Svantesson[1] have observed a 15-Mev gamma ray in their elastic scattering experiments and have associated this line with resonant scattering by the 15.09-Mev level in C^{12}. Using the NBS synchrotron operated at 82 Mev and a NaI detector in a technique similar to that of Fuller and Hayward but with better angular resolution, we have measured the angular distribution of these 15-Mev gamma rays scattered in a 2.32 g/cm² graphite target. This distribution is consistent with the $1+\cos^2\theta$ distribution expected for dipole absorption but is inconsistent with $1-3\cos^2\theta+4\cos^4\theta$ expected for quadrupole absorption. This result establishes this level in C^{12} as a $J=1$ level. The absorption length for these gamma rays in graphite after correction for Compton degraded photons in the target is 2.2 g/cm² in reasonable agreement with Fuller *et al.*[1]

* Supported in part by the U. S. Atomic Energy Commission and the U. S. Air Force, through the Office of Scientific Research of the Air Research and Development Command.

[1] Fuller, Hayward, and Sventesson, Bull. Am. Phys. Soc. Ser. II, **1**, 21 (1956).

N10. On the Gamma-Ray Decay Rate of the 7.65-Mev Level in C^{13}.* W. F. Hornyak, *Princeton University.*—The inelastic scattering of 16 to 20-Mev protons by carbon was used to investigate the ratio of γ-ray de-excitation to α-particle dissociation of the 7.65-Mev level in C^{13}. The inelastic proton spectrum was exhibited on a multichannel analyzer which could be gated by $p'-\gamma$ coincidences. The major difficulty is observing possible $p'-\gamma$ coincidences for the proton group leading to the 7.65-Mev level was the presence of the low-energy tail of the relatively more intense group to the 4.43-Mev level (this level subsequently decays entirely by γ-ray emission). Even at the most favorable incident energy (17.5 Mev) and angle of observation ($\theta_{p'}=150°$) the ungated 4.43 group is 20 times the intensity of the 7.65 group. A strong $p'-\gamma$ angular correlation was discovered for the 4.43 group and was used to *reduce* the effect of this tail by appropriately locating the γ-ray detector. The preliminary result of this investigation gives $\Gamma_\gamma/\Gamma_\alpha<0.03$. The ratio of these two decay rates is of importance in recent conjectures concerning stellar energy sources and the creation of the elements.

* Supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.

N11. Angular Correlation in the Inelastic Scattering of Protons by C^{12}.* R. Sherr and W. F. Hornyak, *Princeton University.*—Peelle[1] has investigated the angular distribution of 14 to 19-Mev protons inelastically scattered by C^{12}. For excitation of the 4.43-Mev (2+) state the distributions are asymmetrical, with forward and backward maxima, clearly indicating at least some noncompound-nucleus effects. Efforts to fit the data with surface scattering have so far been unsatisfactory. Satchler[2] has recently calculated the angular distribution for γ rays following inelastic surface scattering of nucleons. We have measured the (p',γ) angular correlation for the 4.43-Mev state with the proton counter set at $\theta_{p'}=30°$, and 150°, with respect to the 17.5-Mev beam, with the γ counter in the (p,p') plane. These p' angles are in the forward and backward maxima of the inelastic scattering. The angular distributions of the coincidences have essentially the same form at the two p' angles. They are fitted closely by $0.29+\sin^2 2\alpha$, where $\alpha=(\theta_\gamma-12°)$ for $\theta_{p'}=150°$ and $\alpha=(\theta_\gamma-75°)$ for $\theta_{p'}=30°$ (θ_γ is the angle of the γ counter with respect to the beam). Comparison with Satchler's theory will be presented.

* Supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.

[1] R. Peelle, Phys. Rev. **98**, 1184(A) (1955).

[2] G. R. Satchler, Proc. Phys. Soc. (London) **68**, 1037 (1955).

N12. Angular Distribution of Protons from the $C^{12}(He^3,p)N^{14}$ Reaction at 4.5 Mev. R. L. Johnston, E. A. Wolicki, E. H. Geer, and H. D. Holmgren, *Naval Research Laboratory.*—The NRL 5-Mv Van de Graaff generator was used to bombard C^{12} with 4.5-Mev He^3 particles. The protons, which leave the residual nucleus in the ground state, first excited state and second excited state, were recorded at 5-degree intervals from 5 to 155 degrees in Ilford 200-micron *c*-2 emulsions. The resulting angular distributions exhibit the following features: the ground-state group has a forward peak, a minimum in the region of 90 degrees and a maximum near 140 degrees; the first excited state group is strongly peaked in the forward and backward angles with a minimum in the vicinity of 90 degrees; and the second excited state group is similar in shape to the first excited state group with the exception that the yield of protons in the second excited state is of the order of 6 times more intense than that of the ground-state and first excited state groups. These angular distributions differ considerably from the angular distributions at 2-Mev bombarding energy[1] in that at 4.5 Mev the peaks are stronger and narrower.

[1] R. Johnston and H. D. Holmgren, Bull. Am. Phys. Soc. Series II, 1, No. 1, 21 (1956).

Friday Afternoon at 1:15

Sheraton-Park, Exhibit Hall

(J. A. Bearden presiding)

Microwaves and Bands; X-Rays

NA1. Determination of Barriers to Internal Rotation from Microwave Frequencies.* E. Bright Wilson, Jr., Ralph W. Kilb, and C. C. Lin,† *Harvard University.*—The internal rotation of a methyl group in a molecule is known to be hindered by a potential energy of approximately sinusoidal shape. For high barriers, the pure rotation spectrum observable in the microwave region is that of a rigid molecule. For lower barriers, tunneling through the barrier occurs and the molecules in the two resulting torsional levels have slightly different rotational transition frequencies. The spectrum thus consists of doublets whose splitting is a measure of V. The Hamiltonian contains rigid rotor terms, the kinetic energy of rotation of the methyl group, the cross term between internal and over-all rotation, and the potential energy V. The cross term is treated as a perturbation for V moderately large. This enters in the first order for the degenerate torsion level. It contributes in second order in both torsion levels, altering the values of the effective moments of inertia slightly. Both effects are calculable as a function of the barrier. Other perturbations due to the nonrigidity of the separate halves of the molecule,

discussed by Kivelson,[1] do not seem to alter appreciably the barriers derived from ground state observations.

* This research was assisted by the Office of Naval Research.
† Now at the University of Oklahoma.
[1] D. Kivelson, J. Chem. Phys. **22**, 1733 (1954); **23**, 2230 (1955); **23**, 2236 (1955).

NA2. Microwave Spectrum and Barrier to Internal Rotation of Acetyl Fluoride.* LOUIS PIERCE, *Harvard University.*—The microwave spectra of several isotopic species of acetyl fluoride have been measured and analyzed to determine the structure, barrier to internal rotation, and the orientation of the methyl group. The CH_3COF and CD_3COF spectra contain a number of lines which are split into two components because of internal rotation. One component arises from molecules in the lowest nondegenerate torsional state, while the other arises from molecules in the lowest degenerate torsional level.[1,2] These splittings determine the threefold barrier for acetyl fluoride to be 1050 Cal±50 Cal. The spectra of CHD_2COF and CDH_2COF have also been observed. Asymmetric substitution on the methyl group makes possible the determination of the relative orientation of the methyl groups with respect to the −COF group. Analysis of these spectra shows conclusively that this orientation is such that a hydrogen atom of the methyl group is eclipsed by the oxygen atom of the −COF group.

* This research was assisted by the Office of Naval Research.
[1] Wilson, Lin, and Lide, J. Chem. Phys. **23**, 136 (1955).
[2] Wilson, Kilb and Lin, see abstract NA1.

NA3. Microwave Spectrum and Internal Barrier of Acetaldehyde.* RALPH W. KILB AND CHUN CHIA LIN,† *Harvard University.*—The microwave spectra of several isotopic species of acetaldehyde have been studied. The pseudo-rigid rotor spectra of CH_3CHO and CD_3CDO have been previously reported.[1] Further examination of the spectra of these isotopes and of CD_3CHO has been carried out, and with the application of an extension of the theory of Wilson, Lin, and Lide[2,3] the barriers to internal rotation about the carbon-carbon bond have been obtained. The threefold terms are, respectively, 1140±40 cal, 1110±70 cal, 1140±50 cal. Slight discrepancies are still found to exist. The assumption that these discrepancies are due to a sixfold term in the barrier $V=\frac{1}{2}V_3(1-\cos 3\alpha)+\frac{1}{2}V_6(1-\cos 6\alpha)$ leads to the following estimates of V_6: 56 cal, (89) cal, 58 cal. The spectra of CH_2DCHO and CHD_2CHO conclusively confirm the electron diffraction results of Schwendeman and Brockway[4] that the oxygen atom is eclipsed by a hydrogen atom of the methyl group.

* This research was assisted by the Office of Naval Research.
† Now at the University of Oklahoma.
[1] D. H. Baird, Harvard thesis, 1950.
[2] Wilson, Lin, and Lide, J. Chem. Phys. **23**, 136 (1955).
[3] Wilson, Kilb, and Lin, see abstract NA1.
[4] R. H. Schwendeman and L. O. Brockway (private communication).

NA4. Microwave Spectrum of Acetyl Chloride.* K. M. SINNOTT, *Harvard University.*—The microwave spectra of several isotopic species of acetyl chloride have been investigated, and from the observed spectra, the structure, chlorine nuclear quadrupole coupling coefficients, and the barrier to internal rotation have been determined. In the case of CH_3COCl^{35} and CH_3COCl^{37} forty rotational transitions, involving values of J from 1 to 11, have been identified. In addition to the chlorine nuclear quadrupole hyperfine structure most of these transitions occur as doublets, both members of which can be fitted to a pseudo-rigid rotor spectrum. From the rotational constants thus obtained the 3-fold barrier in both these isotopic species was found to be 1350±100 Cal. The values obtained for the chlorine nuclear quadrupole coupling coefficients were: CH_3COCl^{35}: $\chi_{aa}=-58.0$ Mc, $\chi_{bb}=36.4$ Mc, $\chi_{cc}=21.6$ Mc. CH_3COCl^{37}: $\chi_{aa}=-45.5$ Mc, $\chi_{bb}=28.5$ Mc, $\chi_{cc}=17.0$ Mc.

* This research was assisted by the Office of Naval Research and by the California Research Corporation.

NA5. Electronic Structure of the OH Molecule by the Method of Configuration Interaction. A. J. FREEMAN, *MIT.*—Two calculations have been carried out on the OH molecule using different sets of one-particle functions: (1) the set natural to the isolated atoms (AO's) and (2) the orbitals belonging to the molecule (MO's). In (1), using the Hartree-Fock 1*s*, 2*s*, and 2*p* functions for oxygen and the 1*s* state for hydrogen, and keeping the 1*s* oxygen state doubly occupied, all Slater determinants of the appropriate ground state symmetry ($^2\pi$) are found. The non-orthogonality of the basic AO's is handled without approximation by the method of Löwdin.[1] The necessary integrals were calculated on Whirlwind I, the MIT digital computer; all two-center integrals were computed by expanding the hydrogen orbital about the oxygen center (analogously to the method of Barnett and Coulson, Coolidge, Löwdin, etc.). In (2), the molecular orbitals (MO's) are formed as linear combinations of the above AO's with coefficients determined by a modified Roothaan (SCF) procedure, in which the energy of a single Slater determinant is made stationary subject to the "equivalence restriction of Nesbet."[2] A configuration interaction calculation is then made using these MO's as the basic set of one-particle functions. The results of these two calculations are discussed and comparison is made to other calculations.

[1] P. O. Löwdin, Phys. Rev. **97**, 1474 (1955).
[2] R. K. Nesbet, Proc. Roy. Soc. (London) **A230**, 312 (1955).

NA6. Microwave Spectrum and Structure of Sulfuryl Fluoride. D. R. LIDE, JR., AND D. E. MANN, *National Bureau of Standards*, AND R. M. FRISTROM, *Johns Hopkins University.*—The microwave spectrum of sulfuryl fluoride, SO_2F_2, has been reinvestigated[1] with improved sensitivity and resolution. In addition to the lines of the $J=1\rightarrow 2$ and $J=2\rightarrow 3$ transitions of the principal species, a large number of weaker satellites have been observed. Six lines of $S^{34}O_2F_2$ have been identified by means of their temperature dependence; the remaining satellites result from excited vibrational states. The rotational constants are 5134.3, 5073.04, and 5057.04 mc for $S^{32}O_2F_2$ and 5133.7, 5070.00, and 5054.07 mc for $S^{34}O_2F_2$. These data lead to the following structural parameters: $r_{SO}=1.405$ A, $r_{SF}=1.530$ A, $\angle OSO=123°55'$, $\angle FSF=96°8'$. These parameters are in closer agreement with the electron diffraction results[2] than the previous microwave determination.[1] The observed isotope shifts indicate that the effect of zero-point vibrations on the structural determination is small.

[1] R. M. Fristrom, J. Chem. Phys. **20**, 1 (1952).
[2] D. P. Stevenson and H. Russell, J. Am. Chem. Soc. **61**, 3264 (1939).

NA7. *K*-Shell Ionization by Protons of 1.5 to 4 Mev.* P. R. BEVINGTON AND E. M. BERNSTEIN,† *Duke University.*—Previous measurements of *K*-shell ionization cross sections made by Lewis, Simmons, and Merzbacher[1] were in qualitative agreement with the theory of Henneberg.[2] However, the data indicated significant deviations from Henneberg's calculations, especially for high Z, which were attributed to relativistic effects. In the present experiment we have extended the region of Z to include Fe and U. Some of the measured cross sections for ionization are: Fe, 1.55 Mev, 150 barns; 3.90 Mev, 920 barns; U, 2.25 Mev, 1.5 millibarns; 3.75 Mev, 9.2 millibarns. The Auger correction factors used were: Fe, 3.4, and U, 1.0. The U cross sections are about a factor of two to three higher than the theory in agreement with the previous results for high Z. On the other hand, the Fe data are in good agreement with the theoretical predictions, supporting the hypothesis of a relativistic correction for the heavier elements.

* Supported in part by the U. S. Atomic Energy Commission.
† E. I. du Pont de Nemours Fellow 1955–56.
[1] Lewis, Simmons, and Merzbacher, Phys. Rev. **91**, 943 (1953).
[2] W. Henneberg, Z. Physik **86**, 592 (1933).

NA8. Photoelectric Cross Section of Lead at 0.511 Mev.* KARL W. SEEMANN,† *Cornell University.*—The *K*-shell photo-

electric cross section of lead has been measured directly using annihilation radiation from a positron source (Na^{22}). One NaI(Tl) scintillator viewed the source, counting 0.511-Mev gamma rays. A lead foil target was placed on the opposite side of the source at 180° to the gamma-ray counter. The target subtended a larger solid angle than the counter so as to intercept any annihilation quantum whose "twin" was detected in the counter. A coincidence was taken between the gamma-ray counter and another NaI(Tl) scintillator at 90° to the beam in which 75 kev K x-rays from the target were detected. The efficiency of the x-ray counter was measured by using Hg^{203} as a source of x-rays.[1] The beta particle and conversion electron were detected in coincidence in two thin stilbene scintillators and a triple coincidence was formed with the K x-ray. The measured cross section was $\sigma_K = 23.4 \pm 0.7$ barns in agreement with theory.

* Part of a dissertation submitted to Cornell University (February, 1956).
† Permanent address: Aircraft Nuclear Propulsion Department, General Electric Company, Cincinnati 15, Ohio.
[1] I am indebted to Dr. Morton Camac for suggesting this technique.

NA9. Crystal Spectrometer Calibration of a High-Energy X-Ray Intensity Monitor.* H. W. Koch, J. E. Leiss, and J. S. Pruitt, *National Bureau of Standards.*—Preliminary tests have been made of a new technique for the absolute energy calibration of high-energy x-ray monitors. With this method the total number of x-ray photons transmitted through a carbon absorber is determined with a 5-in. diameter, 9-in. long sodium iodide crystal in a good geometry arrangement. Such a spectrometer counts about 96% of the incident photons. If the primary photon spectrum and the carbon absorption coefficients are assumed known, the spectrometer counts can be related to the total energy in the primary x-ray beam. Measurements were made with carbon absorber lengths of 306, 401, and 497 g/cm² for synchrotron energies of 56, 80, and 110 Mev. The data were used to determine a value of 4480 erg/esu/cm for a flat ionization chamber monitor[1] at 80 Mev. The estimated uncertainty is ±4%, mostly due to an inadequate knowledge of the carbon absorption coefficients, to which the calculations are very sensitive. Improved techniques should allow a reduction of this uncertainty. This method allows accurate monitor calibrations with smaller beam intensities than can be used with a calorimeter.

* Supported in part by the U. S. Air Force, through the Office of Scientific Research of the Air Research and Development Command.
[1] P. D. Edwards and D. W. Kerst, Rev. Sci. Instr. **24**, 490 (1952).

NA10. Calorimetric Calibration of a High-Energy X-Ray Monitor.* J. S. Pruitt and S. R. Domen, *National Bureau of Standards.*—A 25r Victoreen thimble in a ⅛-in. lead cap[1] has been calibrated with a synchrotron at peak x-ray energies of 52, 65, and 80 Mev, using a calorimeter modeled after those described by Laughlin *et al.*[2] and by Edwards and Kerst.[3] The calorimeter contains lead cylinders 4 cm in diameter and 7.5 cm long, and was bombarded by a 2-cm diameter beam. Measurements of the energy lost out the sides of the irradiated cylinder showed this to be about 12% of the incident energy. Calculations showed that the cylinder transmitted less than 1% of the incident energy in each case. The r-thimble and r-meter were calibrated to read in esu/cc with a 150 kev x-ray beam. Preliminary results of the experiment are 2800 ±100 (erg/cm²)/(esu/cm³) at 52, 65, and 80 Mev. The calorimeter measurements could be reproduced to within 2%, and the measurements of side scattered energy introduced uncertainties of the order of 2½%. The machine energies quoted are uncertain to within 5%. Comparison measurements were made with a 25r Victoreen thimble in an 11.5-cm Lucite cube,[1] and with a transmission monitor with ¼-in. copper walls.[3]

* Sponsored by the Office of Basic Instrumentation, National Bureau of Standards.
[1] Natl. Bur. Standards Handbook **55**, (1954), p. 30.
[2] Laughlin, Beattie, Henderson, and Harvey, Am. J. Roentgenol. Radium Therapy Nuclear Med. **70**, No. 2 (1953).
[3] P. D. Edwards and D. W. Kerst, Rev. Sci. Instr. **24**, 490 (1952).

NA11. Target Self-Absorption in X-Ray Emission Spectroscopy.* H. P. Hanson, *University of Texas.*—In studying the x-ray emission spectra of the valence electrons in metals it is customary to ignore the self-absorption in the target. It is assumed that electron penetration is so much less than x-rays that this effect will be negligible. Whatever, the validity of this argument, absorption of the x-radiation in the target can occur. Our studies with 6° and 60° target angles show that in many instances the appearance of the emission band due to the valence electrons is determined by the abrupt increase in absorption at the edge. Thus some large asymmetries previously reported in the 1–2 A range do not exist. Furthermore, the top of the filled region does not coincide with the inflection in the absorption curve, it only seems to for small target angles because of the absorption jump. This is not inconceivable since the emission and absorption processes probably do not occur under identical conditons in the metal. Measurements were made on $CuK\beta_5$, $FeK\beta_5$, and $WL\beta_5$, but the possibility of this effect playing a role in the classic experiments on light metals will be discussed.

* Supported in part by the Robert A. Welch Foundation of Texas.

NA12. The X-Ray Intensifier Pick-Up Tube. Bernard R. Linden, *Allen B. Du Mont Laboratories, Inc.*—A modification of the photoconductive television pick-up tube is proposed. which will make such tubes sensitive to x-radiation. In this tube the target, made of a material showing electron bombardment conductivity, is deposited onto a signal plate which is a layer of heavy metal (such as Pt or Au) of a predetermined thickness. The incident x-radiation being absorbed in the signal plate (which acts as an intensifier plate), ejects high-energy electrons which enter the target material and give rise to local variations in conductivity the magnitude of which depends on the incident x-ray pattern. Other than this modification, the tube works similarly to the usual photoconductive camera tubes. Results will be presented of a rough theoretical calculation for the optimum thickness of the signal plate and the expected improvement in signal-to-noise ratio over tubes not employing the intensifier signal plates. Experimental results indicate that for photon energies of the order of 250 kev the intensifier plate is helpful while for lower energies (≈100 kev) there is no improvement in sensitivity or signal-to-noise ratio.

Friday Afternoon at 1:15

Sheraton-Park, Burgundy Room

(F. S. Brackett presiding)

Biophysics

P1. Electron-Spin Resonance in X-Irradiated Proteins.* Walter Gordy and Howard Shields, *Duke University.*—The microwave magnetic resonance method previously described[1] for the study of effects of ionizing radiations on biological substances is extended to other proteins including several enzymes, histone, insulin, hemoglobin, albumin, and a

number of others. The results tend to support the previous conclusions[1] regarding effects of ionizing radiation on proteins. Two types of patterns are obtained either separately or in combination. One is characteristic of cystine and is believed to arise from odd electrons trapped mainly on *S*-atoms, probably in the $S-S$ link; the other is a doublet of ~15 gauss separation and is believed to arise from odd electrons trapped on an oxygen of the $N-H-O$ hydrogen bridges. The cystine-like pattern is sensitive to the strength of the applied field; and the doublet, at least in silk, has been shown to vary with orientation of the sample in the field. The pattern for cysteine is very similar to that of cystine. This could mean that the $S-S$ cystine link is severed by the ionization, but more probably it means the opposite: that hydrogen is eliminated to form ionized cystine from cysteine. The patterns of oxidized and reduced glutathione are noticeably different.

* Supported by the Office of Ordnance Research, Department of the Army.
[1] Gordy, Ard, and Shields, Proc. Natl. Acad. Sci. U. S. **41**, 996 (1955).

P2. Electron-Spin Resonance in X-Irradiated Peptides.* GENE MCCORMICK AND WALTER GORDY, *Duke University.*—Microwave magnetic resonance is being used to study the effects of ionizing radiations on a series of peptides or polypeptides partly as an aid in interpretation of similar results on more complex proteins. X-irradiated glycyl glycyl glycine gave a doublet resonance like that found for glycyl glycine or silk.[1] DL-alanyl-DL-alanine gave a quintet like that for alanine and attributed to the $(C_2H_4)^+$ radical.[1] Acetyl DL-alanine gave a sextet like that found[2] for $Hg(C_2H_5)_2$ and attributed to the C_2H_5 radical. Glycyl-DL-valine and acetyl-DL-leucine gave complex spectra of many lines. They indicate the presence of radicals having protons with unequal coupling and possibly the presence of more than one radical. The pattern of acetyl-DL-leucine is similar to that of iso-leucine[1] and may be the 7-line structure of the $(C_2H_6)^+$ radical with a doublet superimposed. The patterns of DL-alanyl-glycine and DL-alanyl-glycyl glycine are alike and at room temperature appear to be the alanine quintet possibly with a central line superimposed. Many of the patterns became qualitatively different when the samples were cooled to 77°K.

* Supported by the Office of Ordnance Research, U. S. Army.
[1] Gordy, Ard, and Shields, Proc. Natl. Acad. Sci. U. S. **41**, 996 (1955).
[2] W. Gordy and G. McCormick, J. Am. Chem. Soc. (to be published).

P3. Electron-Spin Resonance in X-Irradiated Sugars and Cellulose Fibers.* HOWARD SHIELDS, W. B. ARD, AND WALTER GORDY, *Duke University.*—Electron-spin resonance of the resulting unpaired electrons has been used for study of the effects of ionizing radiations on various sugars and cellulose fibers. The spin resonance pattern most often observed is a doublet of the order of 10 to 20 gauss separation. Some sugars including ribose, gave only a single, fairly sharp resonance. X-irradiated lactose gave a quartet hyperfine structure which may arise from the CH_3 radical. Like the similar ones observed in certain other hydrogen-bonded material,[1] the doublet resonances are believed to arise from electrons localized on oxygens which are involved in hydrogen bridges and which interact mainly through dipole-dipole coupling with the bridging proton. Similar doublets were observed for various x-irradiated woods and cell walls of plants. Purified cellulose, also cotton fiber, gave a more complex structure which, however, may be superposition of similar doublets separated slightly by crystalline field effects.

* Supported by the Office of Scientific Research, U. S. Air Force.
[1] Gordy, Ard, and Shields, Proc. Natl. Acad. Sci. U. S. **41**, 983 (1955).

P4. Electron-Spin Resonance in X-Irradiated Hormones and Vitamins.* HARVEY N. REXROAD AND WALTER GORDY, *Duke University.*—Electron-spin resonance of the resulting unpaired electrons is being used to evaluate the effects of ionizing radiations on various hormones and vitamins. The resonance obtained of progesterone is a triplet similar to that of glycine,[1] and is believed to arise from the $(CH_2)^+$ radical, probably bonded to some other group with no coupling nuclei. Parathyroid gave a doublet resonance of 15 gauss separation similar to that of certain proteins.[1] Hexestrol gave no detectable resonance often prolonged irradiation. Vitamin A, vitamin K-5, and biotin gave only single broad resonances. Ascorbic acid gave a doublet of 20 gauss spacing with a weaker resonance superimposed. The *g*-factors are all very close to the value for the free electron spin. Other similar substances are under investigation.

* Supported by the Office of Scientific Research, U. S. Air Force.
[1] Gordy, Ard, and Shields, Proc. Natl. Acad. Sci. U. S. **41**, 983 (1955).

P5. Absorption Spectra of Some Biological Molecules in the Vacuum Ultraviolet. G. WATTS AND R. SETLOW, *Yale University.**—We have investigated the absorption spectra of various organic molecules in a wavelength range of 1200 to 2000 A. The compounds studied are amino acids, nucleic acids, carbohydrates, and polymers of these substances, such as proteins and DNA. The substances to be analyzed are prepared as thin dry films deposited on calcium fluoride windows. The film thicknesses are in the neighborhood of 1 to 0 $\mu g/cm^2$. The spectroscopic equipment consists of a vacuum monochromator with a 1-meter concave diffraction grating in a radius mounting. The detector is a phosphor coated photomultiplier tube and the light sources are either 65-watt or 1000-watt hydrogen discharge tubes. The characteristic features of the spectra obtained in this way will be given and discussed. Typical absorption cross sections are 5×10^{-2} $cm^2/\mu g$ and ordinarily change by less than a factor of 10 from 1800 to 1300 A.

* Assisted in part by the American Cancer Society on recommendation of the Committee on Growth.

P6. Physical Approach to the Problem of Bacteriophage Injection Mechanism. AADNE ORE* AND ERNEST C. POLLARD, *Yale University.*†—It is currently accepted that a bacterial virus attaches to its host at the tip of its tail, and that the outer coat of the phage is left outside, while the inner part enters the bacterium and there undergoes multiplication. A physical interpretation of this entry will be discussed, in order to demonstrate that the injection of the genetic material may offer nothing extraordinary. The problem is treated essentially as a restricted Brownian motion of a thread of material in a viscous fluid. For T-1 and T-2 phages, the detailed structures of which have been investigated most extensively by various investigators, we arrive at average injection times in the interval from 0.1 to 10 seconds. The present lack of detailed knowledge of the actual physical conditions prevents more precise estimates.

* John Hartford Research Fellow, on leave from University of Oslo.
† Aided by a grant from the John A. Hartford Foundation, Inc.

P7. Radial Structure of Cucumber Virus No. 4. REIN KILKSON AND F. HUTCHINSON, *Yale University.**—An X-ray pattern of this long cylindrical virus has been obtained photographically by Bernal.[1] For higher resolution (200–16 A) and for more accurate intensity measurement, a slit spectrometer with Geiger counter detector was used similar to the setup used by Leonard.[2] An automatic recording system was used to step scan the angular region of about 6°. The virus was oriented in 0.5 mm capillaries. The virus concentration was controlled by variation of *p*H of the solution, viscosity being a primary limitation. The equatorial diffraction pattern of the virus was obtained for different concentrations. This enabled the separation of the interparticle interference effect and the single particle pattern, as the latter is independent of concentration. The interparticle effect was observed only at very small angles, being negligible for the rest of the observed pattern. From the

amplitudes of the single particle pattern a Fourier-Bessel transformation was made, so obtaining the cylindrically averaged electron density as a function of the distance from the axis of the cylinder.

* Supported in part by the National Science Foundation and the John A. Hartford Foundation, Inc.
[1] J. D. Bernal and I. Fankuchen, J. Gen. Physiol. **22**, 147 (1941).
[2] B. R. Leonard, Biochim. et Biophys. Acta **12**, 499 (1953).

P8. Order on Protein Structure. HAROLD J. MOROWITZ, *Yale University.**—The composition of a large number of proteins shows certain uniformities. Grouping the amino acids by structural similarities, one finds classes which are relatively constant from protein to protein and others which are highly variable. In addition, if one examines a series of proteins from a common source (in this case the bacterium *E. coli*) uniformities are noted between the several fractions. These relationships suggest a basic order common to all protein molecules and more particularly a basic order to all protein molecules from a single source. This paper will present the experimental evidence for the preceding statements and a discussion of their consequences for the problem of protein synthesis.

* Supported by the John A. Hartford Foundation, Inc.

P9. The Composition and Radiation Sensitivity of Proteins. RICHARD B. SETLOW, *Yale University.**—Recent work on the direct action of ardiation on proteins has shown that, on the average, one primary ionization inactivates one molecule.[1] Gordy and co-workers have indicated that an ionization produced in proteins leaves a positive hole which is transferred in many cases to the cystine groups of the protein.[2] It has also been shown that the quantum yield for the inactivation of enzymes is very large if the molecules contain a lot of cystine.[3] Most of the exceptions to the "one primary ionization, one molecule rule" cited above are proteins with a large cystine composition. It seems as if the creation of an electron vacancy in the *SS*-bond of cystine leads ultimately to the degradation of the molecule. Possible mechanisms will be discussed.

* Assisted in part by the U. S. Atomic Energy Commission and the American Cancer Society on recommendation of the Committee on Growth.
[1] E. Pollard, *et al.*, Progr. Biophys. and Biophys. Chem. **5**, 72 (1955).
[2] W. Gordy, Proc. Natl. Acad. Sci. U. S. **41**, 983 (1955).
[3] R. Setlow, Biochim. et Biophys. Acta **16**, 444 (1955).

P10. Apparatus for the Bombardment of Biological Samples in a Cyclotron. J. E. DONNELLAN, F. HUTCHINSON, AND R. BRAAMS, *Yale University.**—A device has been constructed for cyclotron irradiation of biological samples. The apparatus permits accurate dosimetry with irradiation in vacuum or in various gases and at different specimen temperatures. The cyclotron beam is diffused by a thin foil and a uniform portion is passed through a collimator onto the sample. Ten samples are placed around a disk mounted on a can in a large bell-shaped chamber. The chamber is insulated and acts as a Faraday cup to measure the true incident beam and eliminate errors due to secondary electrons. The temperature of the samples during irradiation may be controlled by filling the can with liquids at suitable temperatures. The samples are rotated into the beam one at a time by a remotely controlled motor. For times down to one second, the desired exposure is obtained by an electrically operated shutter. For doses requiring a few milliseconds, a disk with an adjustable sector-shaped cutout is rotated across the sample. The chamber is provided with a removable foil so that samples may be irradiated in the cyclotron vacuum or in air or other gases.

* Supported in part by the U. S. Atomic Energy Commission and the Hartford Foundation.

P11. Study of the Entry of Virus Material into the Host by Deuteron Bombardment. ERNEST POLLARD AND JANE SETLOW, *Yale University.**—Radiation studies of the sensitivity of a bacterial virus indicate that the sensitive material is less than the whole virus and is long and thin. By bombarding the complex of virus and bacterium just after the entry of the virus, the sensitive area can be determined. It is some ten times larger than the area in the virus outside. On the other hand, the sensitive volume increases only by a factor of two. A very simple explanation of these data is that the virus material uncoils after entry, thus exposing a larger area to deuteron bombardment, without increasing the total volume. The radiation data indicate that, for T-1 bacteriophage, the uncoiled length is 1.0 micron, while the thickness is approximately 15 A. This thickness is roughly equivalent to one molecule of DNA.

* Aided by a grant from the John A. Hartford Foundation and the U. S. Atomic Energy Commission.

FRIDAY AFTERNOON AT 2:00

Shoreham, West Ballroom

(J. R. PLATT presiding)

Chemical Physics

PA1. Apparatus to Observe the Initial Stages of Growth of Nucleate Bubbles Due to Impulse Heating. E. A. MCLEAN, V. E. SCHERRER, AND C. E. FANEUFF, *Naval Research Laboratory.*—The initial stages of growth of nucleate bubbles and films about repetitive-pulse-heated wires immersed in water at atmospheric pressure have been studied with high-speed photography. A technique of "ordered sampling" allows a time resolution much greater than would be obtained from normal operation of a Fastax high-speed camera. This is accomplished by operating the camera as a strip camera and synchronizing a stroboscopic light source with the heating pulse such that the first light flash following each successive heating pulse is delayed linearly in time from zero up to 200 μsec during a given run. This means that nucleate bubbles or films are observed, during their growth, in intervals of 1 to 2 μsec for successive heating pulses. The time resolution of such an assembly would be comparable to that of a framing camera operating at speeds up to 1 000 000 frames per second. To use this technique it is imperative that the phenomena be repetitive and also fairly reproducible between pulses. There are probably numerious applications of this method other than the study of boiling. Growth data will be shown for boiling about 8-mil nichrome and 3-mil tungsten wire.

PA2. Duration of Atomic Collisions.* OTTO OLDENBERG, *Harvard University.*—The conventional estimate of the duration of an atomic collision is the time required to cover an atomic diameter or, if there is a force of attraction, the period of one molecular vibration. Whereas this estimate is adequate for the duration of a head-on collision, it fails for accentric collisions. These are described by "effective potential curves," which were originally introduced to represent dissociation of

diatomic molecules by rotation and take into account the centrifugal force.[1] These curves, different from the ordinary potential curves, show broad maxima outside of the well-known minima. The maxima slow down or even repel the approaching atoms. A pair of atoms whose energy carries it just to the top of a maximum may even perform a part of an unstable rotation. In the general case of eccentric collisions the durations cover a wide range between the period of a molecular vibration and the much longer period of a molecular rotation.

* Research sponsored by the Air Force Cambridge Research Center.
[1] O. Oldenberg, Z. Physik **56**, 563 (1929).

PA3. Mass Spectrometric Study of Molybdenum Oxide Vapor.* J. BERKOWITZ, M. G. INGHRAM, AND W. CHUPKA, *University of Chicago and Argonne National Laboratory.*—A mass spectrometric technique[1] has been applied to the study of the molecular species evaporating from a molybdenum crucible containing MoO_3 solid in the temperature range 700–950°K. Interpretation of the mass spectrum of the vapor indicated that the major molecular species present were Mo_3O_9, Mo_4O_{12}, and Mo_5O_{15} in the approximate ratios 1.0: 0.3:0.015 at 850°K. Preliminary values for $\Delta H(850°K)$ of vaporization of these species are 80, 93, and 110 kcal/mole, respectively. Other species were not detected and were shown to be less than 1% of the Mo_3O_9. These results contradict previous work,[2] in which no analysis of the vapor was employed and which indicated that the vapor consisted mainly of MoO_3 molecules. However, these results now explain the apparently anomolous value of the ΔS of vaporization calculated from earlier vapor pressure measurements.[3]

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] W. A. Chupka and M. G. Inghram, J. Phys. Chem. **59**, 100 (1955).
[2] G. R. B. Elliott and L. Brewer, UCRL Report No. 1831 (June, 1952).
[3] K. Ueno, J. Chem. Soc. Japan **62**:10, 990 (1941).

PA4. Molecular Species Evaporating from ZrO_2 and $Zr-ZrO_2$ Mixtures.* W. CHUPKA, J. BERKOWITZ, AND M. G. INGHRAM, *Argonne National Laboratory and University of Chicago.*—A mass spectrometric study[1] was made of the vapor effusing from tantalum Knudsen cells containing ZrO_2 and $Zr-ZrO_2$ mixtures. In both cases, the major gaseous species was the ZrO molecule. Copious amounts of TaO vapor were also found in both cases as were minor amounts of ZrO_2 and Zr. Thermodynamic treatment of the preliminary data on Zr, ZrO, and ZrO_2 vapor yielded the following heats of reaction. $\Delta H(2000°K) = -17 \pm 5$ kcal/mole for the reaction $Zr(g) + ZrO_2(g) \rightarrow 2ZrO(g)$. $\Delta H(2300°K) = 155 \pm 8$ kcal/mole for the reaction $ZrO_2(s) \rightarrow ZrO_2(g)$. $\Delta H(2000°K) = 142 \pm 5$ kcal/mole for the reaction $\frac{1}{2}Zr(s) + \frac{1}{2}ZrO_2(s) \rightarrow ZrO(g)$. The dissociation energy of ZrO is then calculated to be 184 kcal/mole or 7.3 ev. Previous experiments[2] on this system in which no analysis of the effusing vapor was made had been interpreted as showing that the major gaseous species in both cases was the ZrO_2 molecule. These results were in error due to the use of a weight loss method which neglected the effusion of species such as TaO.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] W. A. Chupka and M. G. Inghram, J. Phys. Chem. **59**, 100 (1955).
[2] Hoch, Nakata, and Johnston, J. Am. Chem. Soc. **76**, 2651 (1954).

PA5. Experimental Determination of Charge Transfer Cross Sections and Secondary Electron Emissions by Ion Bombardment. S. N. GHOSH AND W. F. SHERIDAN, *Air Force Cambridge Research Center.*—Charge transfer cross sections for the reactions (A^+,CH_4), (A^+,C_2H_4), (A^+, C_2H_6) and the reverse reactions have been determined in the energy range of 100 to 800 ev by a method utilized by the authors.[1] Reactions (A^+,CH_4), (A^+, C_2H_4), and (A^+,C_2H_6) have symmetric character, indicating that ions formed by the charge transfer process are vibrationally excited. The reverse reactions do not possess symmetric character. The method has also been utilized to determine secondary electron emissions from a metal surface by ion bombardment. For ions having the same electronic structure, the emission was found to be inversely proportional to the square root of the ion mass. The emission (y) can be given by a formula, $y = (aV/M^{\frac{1}{2}}) + b$, where V = the energy, M = mass of the ion; a and b are constants depending on the electronic structure of the bombarding ion.

[1] Bull. Am. Phys. Soc. Ser. II, **1**, No. 1, 27 (1956).

PA6. Mean Energy per Ion Pair for Electrons in Helium. W. F. MILLER,* *Purdue University.*—The mean energy per ion pair (W) for electrons absorbed in pure helium gas was calculated using the Fowler integral equation and also the Monte Carlo method. The cross sections employed were derived by careful re-analysis of experimental and theoretical information, making extensive use of the intimate relationship between inelastic scattering cross sections and optical properties. For electron energies above 100 ev, W decreases monotonically, attaining values of 56.1, 47.2, and 46.5 ev/ion pair at 100, 1000, and 2000 ev, respectively. The last value may be compared with experimental values of 42.7[1] and 46.0[2] ev/ion pair for polonium alpha particles. Since atoms in highly excited levels ($n \geq 4$) are converted into molecular ions in two body impacts with normal atoms, W is pressure dependent[3]; at high enough pressures the theoretical value of W is about 43.5 ev/ion pair for 2 kev electrons.

* Now at Argonne National Laboratory, Lemont, Illinois.
[1] W. P. Jesse and J. Sadauskis, Phys. Rev. **90**, 1120 (1953).
[2] T. E. Bortner and G. S. Hurst, Phys. Rev. **93**, 1236 (1954).
[3] R. L. Platzman, Radiation Research **3**, 340 (1955).

PA7. A Scattering Chamber for Charge-Exchange and Ionization Measurements. T. M. DONAHUE, W. H. KASNER,* AND C. B. LEFFERT, *University of Pittsburgh.*—A comprehensive evaluation of the electron capture and loss cross sections of light ions in gases is planned in the energy range from 3 to 100 kev. A versatile collision chamber, in which measurements of cross sections can be obtained by independent methods with no change in the electrode structure, will be described. Provisions have been made to provide a neutral beam in order that the equilibrium method can be employed. The normal slow ion collection method as well as an attenuation method can also be used to obtain the cross sections. A novel method employing a series of identical condensers is used to annul the uncertainty in the beam scattering length and in the initial neutral fraction of the beam, and by insertion of a fine wire grid this collision chamber can be used to measure the ionization cross section of both ions and neutral atoms. The detector used in this work is sensitive to both positive and neutral particles.

* Predoctoral National Science Foundation Fellow.

PA8. Elastic and Thermoelastic Properties of Composite Media.* EDWARD H. KERNER, *University of Buffalo.*—In a continuation of previous work[1] it will be shown how the gross bulk and shear moduli of a composite material consisting of a compact of grains or a suspension of grains may be deduced. The grains are assumed to be perfectly bonded to each other or to the suspending material. By using an averaging process due to Bruggeman, and analyzing the effect of a uniform compression and of a uniform tension on an average grain placed in the uniform average medium (having properties the same as those of the gross composite), a pair of coupled equations for the gross moduli is found for compacted composites. An extension of the averaging technique allows a calculation of the moduli of suspensoid-type composites which includes the results describing compacts when the suspending fluid is made to vanish. The bulk coefficients of linear expansion of the two kinds of composites are found from an analysis of the dilatation and bulk stress for average spherical grains when the

composite as a whole is subjected to some small temperature change. All results are free of any limitation on the number of components.

* Partially supported by the U. S. Atomic Energy Commission.
[1] Edward H. Kerner, Phys. Rev. **99**, 1656 (1955).

PA9. A Generalized Equation for the Ionization of Solid Particles. HARVEY EINBINDER, *General Electric Advanced Electronics Center.*—A generalized formula is derived for the ionization of spherical solid particles of submicroscopic size by allowing for multiple ionization. A system of simultaneous equilibrium equations is set up connecting successive states of ionization. Its solution yields a generalized formula that reduces to the Saha equation when only single ionization can occur. When the particles are multiply ionized, the equation can be simplified by steepest descents to

$$\frac{N_e}{N}=\frac{rkT}{e^2}\ln\left(\frac{K}{N_e}\right)+\tfrac{1}{2}, \quad (N_e/N\gtrsim 3),$$

where N is the number density of solid particles, r their radius, and $K=2(2\pi mkT/h^2)^{\frac{3}{2}}\exp(-\varphi/kT)$. This equation is applied to the observations of Shuler and Weber[1] on the ionization of free carbon particle produced in rich acetylene-oxygen flames. Their data are consistent with $\varphi=4.35$ ev, identical with that of graphite, and particle radii between 60 and 80 A.

[1] K. E. Shuler and J. Weber, J. Chem. Phys. **22**, 491 (1954).

PA10. Concept of Intermolecular Forces in Collisions.* JAMES F. HORNIG† AND JOSEPH O. HIRSCHFELDER.—For polar or electronically excited molecules the concept of intermolecular forces requires clarification. To calculate the equation of state or equilibrium properties it suffices to use intermolecular forces which are averaged over the magnetic quantum numbers, but for nonequilibrium or transpost properties it is necessary to know the intermolecular energy for each separate quantum state. There are many different representations of intermolecular forces, depending on which degrees of freedom are treated quantum mechanically and which classically. The whole concept of intermolecular force becomes nebulous when a large fraction of the collisions are not adiabatic. A semiclassical treatment is developed for describing the trajectories of nonadiabatic collisions in which transitions occur infrequently. For grazing collisions the colliding molecules are loosely coupled and best represented in terms of space-fixed coordinates, but when the molecules approach each other more closely the internal degrees of freedom become tightly coupled, and then the intermolecular forces are best calculated in terms of a body-fixed representation. The collisions with tight coupling are especially important for determining the kinetic theory properties of gases.

* This work was carried out under Contract of the U. S. Atomic Research Commission.
† Now at Du Pont Experimental Station.

PA11. Statistical Mechanics of Liquid-Vapor Equilibrium. B. WIDOM, *Cornell University.*—The configuration integral is approximated by considering contributions only from those configurations in which N_1 particles occupy a volume V_1 and N_2 particles occupy a volume V_2, with $V_1+V_2=V$ (total volume) and $N_1+N_2=N$ (total number of particles). The potential energy associated with each such configuration is taken to be $U=N_1u(V_1/N_1)+N_2u(V_2/N_2)$, where u is a simple function related to the intermolecular force law. This ignores the effect of interfacial tension. The configuration integral is then given by

$$\sum_{N_1=0}^{N}\int_0^1\left(\frac{N}{N_1}\right)V_1^{N_1}V_2^{N_2}e^{-U/kT}d\frac{V_1}{V}.$$

The $p-V$ isotherms derived from this approximate configuration integral are found to be analytic functions of van der Waals type wherever the latter lead to stability or to metastability, but where the analytic functions would give rise to instability the pressure is found to be equal to the constant vapor pressure which satisfies the equal areas criterion. Modifications of the approximation which might eliminate the metastability and might give a cubic, rather than quadratic, coexistence curve, are suggested.

PA12. A Method of Approximate Calculation of the Effective Ionic Radii OD Actinides. N. EFREMOV, *1061 Intervale Avenue, New York, New York.*—The effective ionic radii of actinides[1] may be obtained from the ionic radius of actinium. According to the proposed method of calculation of effective ionic radii[2] the radius of actinium may be determined by means of the following formula:

$$R_i(\mathrm{Ac}^{3+})=(n+8)\times K\times P',$$

where $(n+8)$ is the ordinate, K-abscissa, n-principal quantum number of the corresponding period and $P'=0.0109677$ A, a constant which may be derived from Rydberg constant for atomic hydrogen (109677.7). Thus $R_i(\mathrm{Ac}^{3+})=(6+8)\times 7\times P'=98P'$, $R_i(\mathrm{Ac}^{3+})=1.07$ A. The formula for calculation of the ionic radii of trivalent actinides is as follows:

$$R_i(X)=98P'-(Z-89)P',$$

where Z is the atomic number of any actinide, and 89 is the atomic number of actinium—e.g., $R_i(\mathrm{Am}^{3+})=98P'-(95-89)P'$, $R_i(\mathrm{Am}^{3+})=92P'=1.00$ A. The number of portions of ionic radii directly decreases by 1 with direct increase of atomic number of an element of actinide group by 1. The values calculated by means of this formula ($\mathrm{Th}^{3+}-1.06$, Pa -1.05, U -1.04, Np -1.05, Pu -1.02, Am -1.00 A) are in good agreement with values given by W. H. Zachariasen[3]: $\mathrm{Th}^{3+}-1.08$, Pa -1.06, U -1.04, Np -1.02, Pu -1.01, Am -1.00 A.

[1] For sixfold coordination.
[2] N. Efremov, Phys. Rev. **95**, 614 (1954).
[3] W. H. Zachariasen, Phys. Rev. **73**, 1104 (1948).

PA13. Determination of Crystallization Constants in Aqueous Systems from Cooling Studies. JOHN L. STEPHENSON, *National Heart Institute.*—A theory for determining crystallization constants from the correlation of cooling and microscopic data has been developed. To a first approximation it is found that the rate of phase transformation from water to ice is given by Kt^3, where t is time measured from the start of nucleation. From fitting recorded cooling curves K has been found to be of the order of 10^5 cm^3/sec^4·cm^3 for water and 10^7 for biological tissues in the temperature range -50°C to -90°C; K depends on both the rate of formation of ice crystal nuclei and the rate of crystal growth. Our data on the rate of crystal growth, obtained from electron microscopic data, are imperfect but suggest nucleation rates of the order of 10^{17} to 10^{19} nuclei per cm^3·sec. In addition, from the measured values of K, the cooling rate necessary to cool to the metastable vitreous state of water assumed to exist below -130°C can be predicted and is of the order of several thousand degrees per second. This prediction has been tentatively confirmed in a preliminary correlation of measured cooling rates with electron microscopic data.

PA14. The Infrared Spectra of Rubber and Plastics after Nuclear Irradiation.* W. C. SEARS† AND W. W. PARKINSON, *Oak Ridge National Laboratory.*—The infrared spectra of polystyrene, polyethylene, polybutadiene, GR-S, natural rubber, deproteinized natural rubber, polyvinylchloride and Teflon film were measured before and after irradiation. Irradiations were carried out in vacuum and oxygen atmospheres with Co^{60} gamma rays and reactor radiation. Dosages of the order of 10^8 to 10^{10} radicals were required in these polymers to produce significant changes in their infrared spectra. Radical

changes were produced in the infrared spectra of polymers by irradiation in vacuum and in oxygen. The most significant spectral changes resulting from irradiation in vacuum were in the double bond regions. A post-irradiation effect was observed; as a result of exposure to air following irradiation of the polymers in vacuum, oxidation bands increased in intensity over a period of several weeks. These oxidation products differed from those resulting from irradiation in an oxygen atmosphere. The spectra will be discussed in terms of changes in molecular structure resulting from irradiation.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
† Now at the University of Georgia.

Business Meeting of Division of Chemical Physics

(To be held between papers PA6 and PA7)

FRIDAY AFTERNOON AT 2:00

NBS, East Building

(J. S. KOEHLER presiding)

Solid-State Physics, I, Including Metals

Q1. Measurement of the Lattice Vibration Spectrum of Vanadium by Scattering of Cold Neutrons.* R. S. CARTER, D. J. HUGHES, AND H. PALEVSKY, *Brookhaven National Laboratory*.—The gain in energy of cold neutrons when scattered by crystals gives direct information concerning the lattice vibrations (phonons). For the case of coherent neutron scattering, the energy peaks of the scattered neutrons can be used to obtain the relationship of the frequency to the wave vector of the phonons. In the simpler case of incoherent scattering, such as vanadium, a continuous energy distribution is obtained, which gives directly the energy spectrum of the lattice vibrations in the crystal. The present measurements were made by sending a beam of filtered neutrons ($\lambda > 4$ A) into a polycrystalline vanadium sample and measuring the energy of the scattered neutrons by means of a mechanical velocity selector using a resolution of 10% in wavelength. Most of the neutrons are scattered elastically, but, in addition, a definite group of inelastically scattered neutrons is observed of wavelength in the 1.5 A region. When plotted as $dn/d\omega$ *versus* ω after correction for the Debye-Waller factor and the Boltzmann factor, a distribution is observed that rises approximately as ω^2 for small ω and falls rapidly to zero for large ω's. The high-frequency cutoff gives a Debye temperature of approximately 375°.

* Work performed under contract with the U. S. Atomic Energy Commission.

Q2. Growth Mechanism of Zinc Whiskers and Platelets. G. W. SEARS AND R. V. COLEMAN, *General Electric Research Laboratory* (introduced by B. W. Roberts).—Direct evidence is presented that whisker growth occurs at the tip rather than the base. Platelets are shown to grow by the action of a set of crossed screw dislocations. Whiskers are shown to be free of a screw dislocation component normal to their axis.

Q3. The Specific Heat of Cadmium and Mercury. N. M. WOLCOTT AND P. L. SMITH, *Oxford University, England*.—The specific heats of cadmium and mercury have been measured between 1° and 20°K. The results show that the electronic specific heat of cadmium is $1.5\times10^{-4}\ T$ cal/mole-deg. The values of the Debye θ at absolute zero for cadmium and mercury respectively are 188° and 75°. The Debye θ shows marked temperature dependence for both substances; variations of 60 to 100% are observed in the temperature range covered. In a subsidiary experiment the specific heat of Pyrex glass was found to be $0.075\times10^{-5}\ T^3$ cal/g-deg below 5°K. The irregularity in the specific heat of mercury at 7°K reported by Pickard and Simon[1] has not been confirmed, and the value of the Debye θ at 0°K given by Samoilov[2] (300°) for cadmium appears to be too high. At 20°K the measurements agree favorably with those of other authors.[3–6] The specific heats of the hexagonal elements of group 2 are compared, and it is shown that the differences observed may be interpreted in terms of the varying axial ratios of these elements.

[1] G. L. Pickard and F. E. Simon, Proc. Phys. Soc. (London) **61**, 1 (1948).
[2] B. N. Samoilov, Doklady Akad. Nauk SSSR **86**, 281 (1952).
[3] F. E. Simon and F. Lange, Z. physik. Chem. **134**, 374 (1928) (cadmium).
[4] Craig, Krier, Coffer, Bates, and Wallace, J. Am. Chem. Soc. **76**, 238 (1954) (cadmium).
[5] F. E. Simon, Ann. Physik **68**, 241 (1922); Z. physik. Chem. **107**, 279 (1923) (mercury).
[6] W. F. Giauque and R. H. Busey, J. Am. Chem. Soc. **75**, 806 (1953) (mercury).

Q4. Low-Temperature Stored Energy.* J. W. HENDERSON† AND J. S. KOEHLER, *University of Illinois*.—Polycrystalline 99.999% pure copper specimens were cold worked in compression at liquid nitrogen temperature. Measurements were made of the stored energy released during subsequent warmups to +40°C at a rate of 2°C per minute. The differential calorimetric technique used is similar to the method employed by Overhauser.[1] Energy was observed to be released throughout a temperature range from about −160°C to +20°C. Plots of the rate of energy release *vs* temperature show: (1) no energy release above +20°C, (2) peaks at −25°C and −90°C, and (3) smaller peaks in the vicinity of −120°C and −150°C. The total energy release appears to vary as the three-halves power of the strain with 0.19 cal/g corresponding to $\Delta L/L_0 = 0.71$. About half of this energy is attributable to the −25°C process. The addition of 4.5% zinc was observed to modify the annealing spectrum and obscure the details of the low-temperature processes.

* Supported by the U. S. Atomic Energy Commission.
† Now at the Research Laboratories, Hughes Aircraft Company, Culver City, California.
[1] A. W. Overhauser, Phys. Rev. **94**, 1551 (1954).

Q5. Resistivity of Interstitial Atoms and Vacancies in Copper.* A. W. OVERHAUSER AND R. L. GORMAN, *Cornell University*.—The residual resistivity associated with interstitial atoms or vacancies in copper has been calculated with particular attention paid to the scattering of conduction electrons resulting from lattice distortions surrounding the imperfections. Transition probabilities arising from such atomic displacements were evaluated by the same methods ordinarily used to compute the resistivity of a metal caused by phonon

scattering. Unknown parameters such as the effective electron mass and the electron-lattice interaction constant were eliminated by evaluating the ratio of the strain induced resistivity and the phonon scattering resistivity (known experimentally). The contribution of umklapp processes to the latter resistivity was included. For interstitials the scattering from the distorted lattice is an order of magnitude larger than that from the defect itself. For vacancies it is smaller but still important. Interference between scattering from the defect and the surrounding distortion was calculated and found to be very small. The computed resistivity, (including defect scttering, strain scattering, and interference terms), associated with one atomic percent of interstitials and vacancies are 10.5 $\mu\Omega$ cm and 1.5 $\mu\Omega$ cm, respectively.

* Supported in part by the Office of Naval Research.

Q6. Charge Transfer upon Contact between Metals and Insulators. D. O. VAN OSTENBURG AND D. J. MONTGOMERY, *Michigan State University.*—The equilibrium charge distribution between substances in contact has been calculated for several cases in the one-dimensional approximation, e.g., metal-insulator,[1] metal-semiconductor[1,2] metal-metal.[2] Besides these cases we have considered insulator-insulator and certain additional metal-insulator contacts. The direction of charge transfer is, of course, such as to equalize the Fermi levels. The order of magnitude of the charge and of the effective depth of the charged regions depend on the relative position of the energy bands in contact. Thus, for example, in the metal-insulator case it is possible to have either a large charge density (10^{11} statcoulombs/cm^3 in a thin layer (10^{-8} cm), or small charge density (10^{-1} statcoulombs/cm^3) in a layer (10^{-3} cm). The insulator-insulator cases give rise to a similar distribution. The energy levels in most insulators are too poorly known to permit quantitative comparison with experiment, but the results permit an explanation of many of the observations in static electrification reported by Hersh and Montgomery[3] and by Harper.[4]

[1] N. F. Mott and R. W. Gurney—*Electronic Processes in Ionic Crystals* (Oxford University Press, New York, 1940; 1948), Chap. 5.
[2] H. Y. Fan, Phys. Rev. **61**, 365 (1941); **62**, 388 (1942).
[3] S. P. Hersh and D. J. Montgomery, Textile Research J. **25**, 279 (1955).
[4] W. R. Harper, Proc. Roy. Soc. (London) **A218**, III (1953).

Q7. The Elastic Constants of Magnesium and Magnesium Alloys.* T. R. LONG† AND CHARLES S. SMITH, *Case Institute of Technology.*—The adiabatic elastic constants of single crystals of magnesium and dilute alloys of magnesium with Ag, In, and Sn have been measured by the ultrasonic pulse echo technique. The values obtained for pure magnesium are: $C_{11}=0.597$, $C_{33}=0.617$, $C_{44}=0.164$, $C_{12}=0.262$, $C_{13}=0.217$ all expressed in units of 10^{12} dyne cm^{-2}. The alloy results show that within the experimental uncertainty all constants exhibit a smooth behavior as the electron concentration is increased to 2.020 per atom, through the critical region where zone overlap is thought to occur in the c-direction. At most, a small change in slope could be read into the data for $C_{11}+2C_{33}+C_{12}-4C_{13}$ at the critical electron atom ratio of 2.01. This behavior is in contrast to what might be expected from an extension of Leigh's predictions[1] for the elastic constants of aluminum alloys.

* Supported by the Office of Naval Research.
† Now at Bell Telephone Laboratories.
[1] R. S. Leigh, Phil. Mag. **1**, 139 (1951).

Q8. Uniaxial and Hydrostatic Deformation of Snow. J. K. LANDAUER, *Snow Ice and Permafrost Research Establishment.*—Snow consists of a network of randomly distributed anisotropic ice particles. The comparison of strain rates under uniaxial and hydrostatic stresses leads to some understanding of the deformation process in such a porous medium. Strain rates as a function of stress in the region $\sigma=0.25$ to 2 kg/cm^2 can be expressed as $\dot{\epsilon}\propto\sinh\sigma/\sigma_0$, where $\sigma_0\cong0.68$ kg/cm^2 for both uniaxial and hydrostatic stresses. The temperature dependence in the two cases is expressed by the same activation energy, $\Delta H\cong12\,000$ cal/mole. The linear deformation rate for the uniaxial case is about three times greater than the linear deformation rate for the same hydrostatic stress. These results are interpreted as indicating that both uniaxial and hydrostatic deformation are the result of a shear process occurring between the ice particles.

Q9. Performance Characteristics of Solid-State Light Amplifiers. JENNY E. ROSENTHAL, *Allen B. Du Mont Laboratories, Inc.*—The solid-state light amplifier discussed here is of the type that consists of an electroluminescent panel in series with a photoconductor acting as a valve. A feedback arrangement may be provided. The photoconductor has ohmic (I–V) response even though its ac impedance is somewhat greater than its dc resistance and is independent of the frequency. Its conductivity $G\propto L^n$ (L=intensity of incident radiation). The light output $B\propto V^m$ (V=applied voltage). It is shown that for such a light amplifier B will be linear with L (i.e., contrast will be preserved) provided $mn=1$ and G is small as compared with the conductance (capacitive) of the electroluminescent panel. When the light amplifier operates with feedback as a storage device, the condition $mn=1$ is shown to give monostable operation above a threshold voltage, which may or may not be a function of the frequency. Other conditions of monostable operation are discussed. In all cases studied the type of stability above the threshold voltage depends solely on m and n and cannot be changed by operating conditions.

Q10. Luminescence and Photoconductivity of Crystalline AgCl.* D. A. WIEGAND, *Cornell University.*—The intensities and the decay processes of the luminescence and the photoconductivity of AgCl have been simultaneously investigated between 4°K and 200°K. The decrease of the luminescence intensity with increasing temperature can be attributed to a competing recombination process, not accompanied by visible radiation, but having a thermal activation energy of $E=0.05$ ev. The temperature dependence of the decay times is not monotomic, but shows maxima. These maxima can be explained in terms of a model in which energy is transported from the site of absorption to the luminescence center by mobile holes and electrons. Delay in this energy transport is caused by hole and electron trapping and the temperature dependence of the delay determines the temperature dependence of the decay times. Decay curves calculated on the basis of this model are in agreement with the observed curves. The relative magnitudes of the luminescence and photocurrent decay times indicate that if the major portion of the photoconductivity is due to electron motion, then luminescence occurs when a hole is captured.

* Supported first by the Research Corporation of New York and later by the Office of Naval Research.

Q11. Photoconductive CdS Powder Layers. P. W. KRUSE, *Farnsworth Electronics Company.*—Measurements of the photoconductivity of Cu- and Cl-doped CdS powder similar to that reported by Thomsen and Bube[1] have been made. The powder is mixed in ethyl cellulose and deposited on glass between evaporated Al electrodes of gap length 5.0 mm and gap width 0.5 mm. At 300 v dc applied the dark current is 1×10^{-9} amp. With 7 ft-c w illumination falling directly on the gap the photocurrent at 300 v dc applied is 4×10^{-4} amp. The photocurrent is proportional to the 0.6 power of the illumination and the square of the applied voltage. The observed time constant is 10^{-3} sec measured at 2.7×10^{-4} amp photocurrent. The spectral photoresponse extends beyond 8000 A.

[1] S. M. Thomsen and R. H. Bube, Rev. Sci. Instr. **25**, 664 (1955).

Q12. Photoconductivity in KBr and KI.* NICOLAS INCHAUSPÉ, *University of Illinois.*—The photoconductivity of KBr and KI crystals containing additive *F*-centers has been investigated at the temperatures of liquid nitrogen.[1] Photon energies between 2 ev and 5.8 ev were used. Photocurrents are observed which are interpreted as being the result of the ionization of *F*-centers by excitons. The excitons are created on absorption of photons in the tail of the fundamental absorption band of the crystal. The behavior of the photocurrent as a function of *F*-center concentration between 10^{14} cm^{-3} and 10^{17} cm^{-3} permits the lifetime of the excitons to be estimated as approximately 10^{-9} sec.

* Assisted by the Office of Naval Research.
[1] Nicolas Inchauspé, Phys. Rev. **98**, 1550 (1955).

FRIDAY AFTERNOON AT 2:00

Shoreham, Main Ballroom

(E. P. WIGNER presiding)

Invited Papers in Nuclear Physics

QA1. On the Theory of Alpha Disintegration. H. A. TOLHOEK, *University of Leyden, Netherlands.* (30 min.)

QA2. Fission Physics. D. J. HUGHES, *Brookhaven National Laboratory.* (30 min.)

QA3. Recent Work on Cosmic Rays at the University of Bristol. M. W. FRIEDLANDER, *University of Bristol, England.* (30 min.)

QA4. Recent Work on Cosmic Rays at the University of Milan. G. OCCHIALINI, *University of Milan, Italy.* (30 min.)

QA5. The Masses of *K*-Mesons and the Energies of Their Secondaries. W. H. BARKAS, *University of California, Berkeley.* (30 min.)

FRIDAY AFTERNOON AT 1:15

Sheraton Park, Continental Room

(M. GOLDHABER presiding)

Radioactive Nuclei, III: Isomers, Aligned Nuclei

R1. Five New Isomers with Half-Lives in the Microsecond and Millisecond Region.* STANLEY H. VEGORS, JR., AND R. B. DUFFIELD, *University of Illinois.* A technique has been developed for the detection of photoinduced radioactivity between the x-ray yield pulses of the University of Illinois 22-Mev betatron.[1,2] The following additional elements have been surveyed for radioactivity in the microsecond and millisecond half-life region: Si, V, Co, Ge, Se, Br, Nb, Rh, Ag, In, Sn, Cs, Pr, and Pt. Five new radioactivities have been observed; these elements, gamma-ray energies, and half-lives are as follows: Br, 152±10 kev, $130\pm20\times10^{-6}$ sec; Br, 264±15 kev, approximately 30×10^{-6} sec; Nb, 88±5 kev, $6\pm1.5\times10^{-6}$ sec; In, 312±10 kev, $45\pm10\times10^{-3}$ sec; and Sn, 503±15 kev, $185\pm30\times10^{-6}$ sec.

* This work was supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] S. Vegors and P. Axel, Phys. Rev. **100**, 1238(A) (1955).
[2] S. Vegors and P. Axel, Phys. Rev. (to be published).

R2. Excitation of Isomers by High-Energy X-Rays.* M. G. STEWART, A. J. BUREAU, AND C. L. HAMMER, *Iowa State College.*—A search for new isomeric states with half-lives greater than 5×10^{-6} sec has been made using the x-ray beam from the Iowa State College Synchrotron to excite the reactions. Twenty-three elements including the naturally occurring rare earths (europium excepted) have been examined. Four previously unreported activities were found. The elements, gamma-ray energies and half-lives are as follows: W, 353 kev, 14.2×10^{-6} sec[1]; Lu, 120 kev, 70×10^{-6} sec; Ho, 305 kev, ~1 sec; Tb, 44-kev x-ray, half-life as yet not measured. A 210-kev state with a half-life of approximately 1 sec has also been observed in Er.[2] The energies and half-lives of the known isomeric states in Y^{88m} and Zn^{67m} were also measured to check the validity of the experimental approach.[3]

* This work was supported by the U. S. Atomic Energy Commission.
[1] The energy and half-life of the isomeric state in W were reported by Stanley Vegors and Peter Axel while this work was in progress.
[2] Hollander, Perlman, and Seaborg, Revs. Modern Phys. **25**, 469 (1953).

R3. Highly Forbidden *E*1 Transition ("*K*-Isomerism"). G. SCHARFF-GOLDHABER, M. MCKEOWN, AND J. W. MIHELICH,* *Brookhaven National Laboratory.*†—A closer investigation of the 57-kev isomeric transition in Hf^{180m} (5.5 hr) has been carried out. The relative intensities of the *L*-conversion electron lines and the absolute conversion coefficients are compatible only with a transition which is predominantly *E*1. This transition is $\sim10^{15}$ times slower than expected on Weisskopf's formula. This may be connected with the fact that the transition takes place from a 9-state to a rotational state (8+) and is therefore highly "*K*-forbidden"[1] ($\Delta K=9$). To exclude the possibility that the *E*1-transition is preceded by a hidden isomeric transition of low energy, a search was made for a competing crossover *E*3-transition from the 9-state to the rotational state 6+. Such a transition of the expected energy (501 kev) was indeed found, both in the internal conversion spectrum and in the unconverted γ-ray spectrum, with an intensity of ~20%. This corresponds to a transition probability $\sim10^9$ times smaller than given by the Weisskopf formula.

* Now at Notre Dame University.
† Under the auspices of the U. S. Atomic Energy Commission.
[1] A. Bohr and B. Mottelson, Dansk. Videnskab. Selskab. Math.-fys. Medd. **29**, No. 9 (1955).

R4. Concerning Transition Probabilities for Low-Energy *E*1 Transitions in the Heavy Region.* JOHN O. RASMUSSEN AND DONALD STROMINGER, *University of California, Berkeley.*—The results of *E*1 transition lifetime measurements by the delayed coincidence method among the actinide elements indicate an erratic variation of *E*1 transition probabilities in this region with many "slow" transitions. The slowest of these *E*1 transitions is of the order of 10^5 to 10^6 times slower than the Weisskopf[1] formula would predict. Nilsson's[2] wave functions for a spheroidal nuclear well were used to calculate *E*1 transition probabilities for several cases of interest. These calculations show that in general the low-energy *E*1 transition prob-

abilities are at least 100 times smaller than the Weisskopf estimate. These calculations thus give a qualitative explanation of the experimentally observed retardations, although quantitative explanations of specific cases cannot be claimed. In the limit of large prolate spheroidal deformation of the nucleus, most of these $E1$ transitions are forbidden because of selection rules in μ_Z or Λ, similar to the selection rules discussed by Alaga[3] for beta decay. In the limit of small spheroidal deformation, these $E1$ transitions are forbidden by selection rules involving j.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] J. M. Blatt and V. F. Weisskopf, *Theoretical Nuclear Physics* (John Wiley and Sons, Inc., New York), p. 627.
[2] S. G. Nilsson, Kgl. Danske Vedenskab. Selskab, Mat. fys. Nedd. **29**, No. 16 (1955).
[3] G. Alaga, Phys. Rev. **100**, 432 (1955).

R5. Precision Measurement of the Lifetime of the 247-kev Cd^{111} State.* P. C. SIMMS AND R. M. STEFFEN, *Purdue University.*—A precise measurement of the lifetime τ_N of the 247-kev state of Cd^{111} seems desirable in view of its significance in evaluating the many experiments on the extranuclear effects on the directional correlation of the Cd^{111} gamma-gamma cascade. Using the gamma-gamma coincidence-spectrometer described elsewhere[1] delayed coincidences were measured. Special precautions were taken to minimize the effects of the high-frequency attenuation in the delay cables on the lifetime measurements. The extranuclear effects on the directional correlation of the cascade which influences the lifetime determination were either taken into account or eliminated by a proper choice of sources or by a special arrangement of the scintillation detectors. The value obtained in this way is $\tau_N=[122.3(-0.8, +1.8)]$ millimicroseconds or $T_{\frac{1}{2}}=[84.9(-0.5, +1.3)]$ millimicroseconds, in good agreement with the earlier reported less accurate measurements.[2]

* Supported in part by the U. S. Atomic Energy Commission.
[1] H. Paul and R. M. Steffen (to be published).
[2] R. M. Steffen, private communication quoted in Aeppli, Albers-Schonberg, Frauenfelder, and Scherrer, Helv. Phys. Acta **25**, 346 (1952).

R6. Isomeric Transition in Cd^{113m}. E. DER MATEOSIAN AND M. GOLDHABER, *Brookhaven National Laboratory.**—Cd^{113m} (5.1 yr)[1,2] is known to decay with the emission of 570-kev β rays to In^{113}. By producing this isomer from enriched[3] Cd^{112}+pile neutrons and comparing its radiations with those from Cd^{109} (470 d) we have established that the previously reported[1] x-rays are due to Cd^{109} impurity present in varying amounts depending on the age of the sample. A well-aged sample of Cd^{113m} showed a 265-kev γ ray above a bremmspectrum with an intensity of $\sim$0.1% of the beta rays. This γ ray is interpreted as the isomeric transition in Cd^{113m}, $h_{11/2}\rightarrow s_{1/2}$. Its energy is compatible with expectations from isomer energy systematics.[3] Its partial lifetime ($\sim$5000 yr) corresponds to an $E5$ transition with an $|M|^2\approx 1/15$. The energy difference of the isobaric pair $Cd^{113}-In^{113}=305$ kev is compatible with expectations from β-ray energy systematics.[4]

* Under the auspices of the U. S. Atomic Energy Commission.
[1] Carss, Gum, and Pool, Phys. Rev. **80**, 1028 (1950).
[2] M. Goldhaber and R. D. Hill, Revs. Modern Phys. **24**, 179 (1952).
[3] Obtained from Stable Isotopes Branch, Oak Ridge.
[4] K. Way and M. Wood, Phys. Rev. **94**, 119 (1954).

R7. K-Conversion and K/L Ratios in Te^{121} and Te^{123}.* N. GOLDBERG, *Washington University.*—The K-conversion coefficient and K/L ratio of the predominantly $M1$ transition to the ground state of Te^{121} and Te^{123} were determined from electron-intensity measurements made with a beta-lens spectrometer. The determination of the coefficient is based on the assumption of complete internal conversion of the $M4$ radiation in cascade with the transition to the ground state. This introduces negligible error since the conversion coefficient is greater than 1000. The K-shell conversion coefficient is then

$$\alpha_K=\frac{N_2(K)}{N_2(\gamma)}=\frac{N_2(K)}{N_1-N_2},$$

where $N_2(K)$ and $N_2(\gamma)$ are the number of K-conversion electrons and gamma rays from the ground-state transition and N_1 and N_2 is the total number of conversion electrons (K, L, M, etc.) in the first and second transition, respectively. The results were 0.072 ± 0.003 and 0.165 ± 0.005 for Te^{121} and Te^{123}, respectively. The theoretical values taken from the privately circulated tables of Rose and Goertzel, which include effect of shielding, are 0.074 and 0.171 for these same isomers. The K/L ratios in Te^{121} and Te^{123} were found to be 6.3 ± 0.3 and 6.6 ± 0.3 which are to be compared with the theoretical values of 7.98 and 7.87, respectively.

* Supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission.

R8. Alpha-Particle Emission from Oriented Np^{237} Nuclei and the Spheroidal Shape of this Nucleus. L. D. ROBERTS, J. W. T. DABBS, G. W. PARKER, AND R. D. ELLISON, *Oak Ridge National Laboratory.*—Bleaney *et al.* have made a microwave study of the energy levels of the NpO_2^{++} ion in the rhombohedral crystal $NpO_2Rb(NO_3)_3$ in which all of the linear NpO_2^{++} groups lie parallel to the crystalline c-axis. Assuming their results, we calculate a nuclear alignment along the c-axis described by $\Delta=0.043/T+0.0080/T^2$ where $\Delta=(\langle I_c^2-I(I+1)/3\rangle_{Av})/I^2$, I_c is the c-axis projection of the nuclear spin, and T is the absolute temperature. Observation of the angular distribution, $W(\theta)$, of the intensities of α-particle emission from such a crystal relative to the c-axis as a function of temperature should then reveal any dependence of the α emission on the spatial orientation of the nuclei. An experiment of this type has been done. Measuring θ from the c-axis, the angular distribution was proportional to $(1+G(T)P_2(\cos\theta))$, where $G(T)$ was found to be proportional to Δ within the experimental error and was -0.068 at 1.1°K. The distribution corresponds to a maximum in the direction perpendicular to the c-axis, in disagreement with a suggestion of Hill and Wheeler,[1] based on the spheroidal nuclear shape. The distribution may be understood in terms of the angular momenta involved.[2]

[1] D. L. Hill and J. A. Wheeler, Phys. Rev. **89**, 1133 (1953).
[2] Dabbs, Roberts, and Parker, Bull. Am. Phys. Soc. Series II, **1**, No. 4, 207 (1956).

R9. Alpha-Particle Emission from U^{233} Nuclei Aligned by the Pound Method. J. W. T. DABBS, L. D. ROBERTS, AND AND G. W. PARKER, *Oak Ridge National Laboratory.*—Pound[1] has proposed nuclear alignment through the interaction of the nuclear quadrupole moment with a crystalline electric field gradient. Eisenstein and Pryce[2] have suggested that the $6d$ bonding orbitals in UO_2^{++} and NpO_2^{++} should be similar. Assuming similar magnitudes for the nuclear quadrupole moments of U^{233} and Np^{237}, the results of the preceding abstract and of Bleaney *et al.*[3] suggest that a substantial Pound nuclear alignment might be obtained by cooling $U^{233}O_2Rb(NO_3)_3$. This expectation has been confirmed experimentally. An experiment similar to that of the preceding abstract has been performed, using a single crystal of $U^{233}O_2Rb(NO_3)_3$ coated with a layer of U^{233}-rich material which contained 0.2% Np^{237} to provide a magnetic nuclear spin-lattice relaxation mechanism. The angular distribution of the α-particle intensity and its temperature dependence were found to be similar to that observed for Np^{237}, and may be approximately described by $1-(0.06\pm0.01)P_2(\cos\theta)$ at 1.1°K, with a possible small $P_4(\cos\theta)$ term.

[1] R. V. Pound, Phys. Rev. **76**, 1410 (1949).
[2] J. C. Eisenstein and M. H. L. Pryce, Proc. Roy. Soc. (London) **A229**, 20 (1955).
[3] Bleaney, Llewellyn, Pryce, and Hall, Phil. Mag. **45**, 992 (1954).

R10. Interpretation of Alpha-Particle Emission from Aligned Nuclei. M. E. ROSE, L. D. ROBERTS, AND J. W. T. DABBS, *Oak Ridge National Laboratory.*—The observed angular

distributions[1] show that elementary considerations of barrier penetrability are inadequate. The results can be explained in terms of the angular momentum properties of the emitted radiation and of the nuclear states involved. The dynamics of the spheroidal nucleus and the problem of barrier penetrability are pertinent for the total decay constant and for the relative intensities of different partial waves (L_α) of the emitted alphas. When more than one value of L_α is important, the *shape* of the distribution depends on nuclear parameters δ measuring the relative amplitudes. In the neighborhood of 1°K ($kT \gg$ coupling energy E) the distributions are almost exactly $1+A_2P_2(\cos\vartheta)$ where $A_2=G_2N_2$ and $G_2(\sim E/kT)$ depends only on the emitting state and the spin coupling. N_2 depends on L_α, the final state, and on δ. At lower temperatures a term A_4P_4 becomes appreciable for some final states, quite generally, $A_4 \sim (E/kT)^2$ in first approximation. Low-temperature measurement of the anisotropy (G_2 *vs* T) provides a value of the quadrupole coupling Q when an adequately large hyperfine coupling is also present. This is possible independently of the decay scheme. When only quadrupole coupling is present and there is interference between different L_α, it may not be feasible to establish more than a lower limit for Q. This possibility may depend on the assignment of parity change characteristic of the interfering partial waves.

[1] Roberts, Dabbs, Parker, and Ellison, Bull. Am. Phys. Soc. Series II, **1**, No. 4, 207 (1956); Dabbs, Roberts, and Parker, Bull. Am. Phys. Soc. Series II, **1**, No. 4, 207 (1956).

FRIDAY AFTERNOON AT 1:15

Sheraton Park, Caribar-Mural Room

(M. L. GOLDBERGER presiding)

Theoretical Physics, IV: Field Theory, Strange Particles

RA1. Einstein's Generalization of the Gravitation Theory and the Maxwell-Lorentz Theory of Electromagnetism. PARVIZ MERAT, *University of Maryland.*—The Einstein generalization of the gravitation theory is extended to include the so-called cosmological term. Following Anderson and Merat[1] it is assumed that the theory is gauge invariant. $\eta^{\mu\lambda\rho}R_{\lambda\rho,\mu}$ is taken to be the current density. The identities associated with the invariance of the theory under a general coordinate transformation are derived. Two equivalent sets of nontrivial identities are obtained. $R_{\mu\nu}$ is taken to be a matter tensor. By means of an approximation method the Maxwell theory of electromagnetism is deduced. A coordinate condition is introduced and the nontrivial identities associated with the invariance of the theory under a general coordinate transformation are reduced to the form of the Lorentz laws of motion for charged matter.

[1] J. Anderson and P. Merat, Phys. Rev. **99**, 1871 (1955).

RA2. Canonical Transformations and Commutators in the Lagrangian Formalism.* IRWIN GOLDBERG, ALLEN JANIS, EZRA NEWMAN, AND PETER G. BERGMANN, *Syracuse University.*—Canonical transformations in configuragion space[1] depend not only on the generator but also on the Lagrangian, and so do the restrictive conditions on the generators themselves. Because the Lagrangian changes under canonical transformations, the canonical transformations will form a group only if a single transformation (group element) is defined as dependent on the form of the Lagrangian. The resulting group possesses commutators but is much larger than would be a group whose Lie algebra would resemble the operator algebra of a quantum theory. A considerably smaller group, just of the right size, consists of all those canonical transformations that leave the form of the Lagrangian unchanged (invariant transformations). Their commutators, if expressed in terms of the generators, turn out to be equivalent to generalized Dirac brackets.[2] In this approach the generators are restricted to be constants of the motion, but this restriction does not defeat the purpose of the investigation, to obtain a Lie algebra of the right structure to serve as a point of departure for quantization.

* Supported by the Office of Naval Research and the National Science Foundation.

[1] P. G. Bergmann and R. Schiller, Phys. Rev. **89**, 4 (1953).
[2] P. G. Bergmann and I. Goldberg, Phys. Rev. **98**, 531 (1955).

RA3. Lagrangians of High Differential Order.* PETER G. BERGMANN, *Syracuse University.*—The restriction to invariant canonical transformations (see preceding abstract) suggests the generalization of the formalism to Lagrangians possessing higher than first derivatives and, in the limit, Hamiltonian principles that are functionals of the field rather than integrals over locally defined Lagrangian densities. It turns out that one can define generators of infinitesimal (invariant) canonical transformations whenever the variation of the Hamiltonian principle functional may be put in the form of a volume integral plus a surface integral, each containing the variations of the field variables as factors. The commutator of two such transformations is a transformation of the same kind and defines a commutator bracket for the corresponding generators. This formalism is closely related to Ostrogradsky's procedure[1] and may have application to Lorentz-invariant subtraction formalisms.

* Supported by the National Science Foundation and the Office of Naval Research.

[1] Ostrogradsky, Mém. Acad. St.-Pét. **6**, 385 (1850).

RA4. Spins of Relativistic Fields. DAVID FINKELSTEIN, *Stevens Institute of Technology and New York University.*—It is shown that both special and general relativity admit of purely gravitational structures having spin one-half and Fermi statistics in the quantized theory.

RA5. Renormalization of Electrodynamics. G. R. ALLCOCK, *National Research Council, Ottawa.*—The Salam-Dyson term by term subtraction prescriptions for overlaps need not be formulated *a priori* so far as we deal only with electrodynamics. They can instead be generated very simply by iterating a suitable set of integral equations, thus making the equivalence with renormalization quite evident. Let A represent all Compton effect graphs of the type used by G. Takeda [Prog. Theoret. Phys. **7**, 359 (1952)]. We have $\Gamma=(1-L)\gamma-\Gamma D'S'A$. This equation is used to eliminate $(1-L)\gamma$ from the vertex b in the familiar expression for the electron self-energy, thus $\Sigma=e^2\Gamma D'S'\Gamma+e^2\Gamma D'S'AD'S'\Gamma-iZ_2\delta m-i(1-Z_2)(p-m)$, e being the observed charge. To use these equations we replace $-L\gamma$ by the value of $\Gamma D'S'A$ with $p=m$, $k=0$, and then iterate to express Γ as a renormalized power series in A. On substituting this series into the above expression for Σ, all overlaps appear automatically with the correct subtractions.

Closed loops present no obstacle to a similar treatment of the photon self-energy.

RA6. On the Possibility of an Isobaric Singlet π Meson.* B. J. MALENKA AND E. FEENBERG, *Washington University.*—The hypothesis of Fermi and Yang[1] that the π meson can be viewed as a composite system of a nucleon and antinucleon is extended to include isobaric spin. The resulting compound system consists of isobaric triplet ($T=1$) and singlet ($T=0$) states. Limiting ourselves to states of total angular momentum 0 or 1, the existence of a bound $^1S_0$, $T=1$ state is assumed and identified with the usual three pseudoscalar pions. From this point of view, the possible existence of a bound $T=0$ state also is suggested. If, as in the above and nuclear problems, we restrict ourselves to wave functions that are totally antisymmetric under space, spin, and isobaric spin exchange, the possible $T=0$ state is the $^3S_1$ or the $^1P_1$ state which can be respectively interpreted as a neutral pseudovector or vector π meson. The requirement of invariance under charge conjugation shows that either meson can be expected to undergo three rather than two gamma decay. A preliminary survey indicates that the existence of a $T=0$, neutral π meson is not precluded by past experiments. Possible implications with respect to nuclear forces, pion-nucleon scattering, and bound hyperons will be discussed.

* Supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] E. Fermi and C. N. Yang, Phys. Rev. **76**, 1739 (1949).

RA7. Question of Vectorial Strangeness. D. C. PEASLEE, *Purdue University.**—It is not clear from present experiment or theory whether the V-particle strangeness number a should be viewed as a scalar or as the z-component of another vector like **t**. Direct observations bearing on this question appear difficult: e.g., the decay possibility $\Xi^- \rightarrow \beta^- + \nu + n$, reactions like $K^- + n \rightarrow \Xi^- + K^+$, proof of τ^0 nonexistence. The assumption of vectorial **a**, whether realistic or not, appears formally convenient in some cases.

* Assisted by the United States Air Force through the Air Force Office of Scientific Research, Air Research and Development Command.

RA8. Classification of Elementary Particles. BANKS H. MEBANE, *The George Washington University.*—A classification scheme for elementary particles and selection rules for transitions are presented. The result contains the Gell-Mann system for meson-baryon multiplets and transitions,[1] and also includes the leptons. Interactions are considered in four classes: strong, electromagnetic, weak, and forbidden. Charge multiplets are defined by numbers called "charge indicators" such that $Q=I^H+\frac{1}{2}$, I^B, and $I^L-\frac{1}{2}$ for nucleons, pions, and electrons and neutrinos. These relations are relaxed for the heavy baryons, mesons, and the muon by the Gell-Mann "strange particle constant." Neutrinos are taken as distinguishable, and charge and the fermion number are conserved; this results in separate conservation of baryons and leptons, with suitable choice of particle states. Isotopic spin I is so defined that $I_3=I^H$ for baryons and I^B for bosons; it is unnecessary to define I for leptons. The system is constructed with no reference to interaction dynamics, but the selection rules provide for certain features which have not been satisfactorily explained in interaction theory; for example, the non-occurrence of electronic pion decay.

[1] *Proceedings of the Fifth Annual Rochester Conference* (Interscience Publishers, Inc., New York, 1955), pp. 133 ff.

RA9. Simple Considerations Relating Strange Particle Lifetimes. M. L. STEVENSON AND A. H. ROSENFELD, *University of California, Berkeley.*—Considerations of phase space can give a qualitative comparison of the decay rates R of different strange particles. The ratios of strange particle lifetimes compared with the ratios of final state phase spaces are summarized below.

	Phase space ratios	Observed lifetime ratios
1.	$R(\tau\rightarrow 3\pi)/R(\theta\rightarrow 2\pi)=10^{-4}$ to 10^{-3}	$\tau_{\theta^0}/\tau_{\theta'}\rightarrow 3\pi \approx \tau_{\theta^0}/10\tau_{\tau} \approx 10^{-2}$
2.	$R(\Lambda\rightarrow n+\pi)/R(\theta\rightarrow 2\pi)=1.1$	$\tau_{\theta^0}/\tau_{\Lambda^0}=0.4_{-0.1}{}^{+0.2}$
3.	$R(\Sigma\rightarrow n+\pi)/R(\theta\rightarrow 2\pi)=2.6$	$\tau_{\theta^0}/\tau_{\Sigma^-}=5_{-2}{}^{+5}$
4.	$R(\Xi\rightarrow\Lambda+\pi)/R(\theta\rightarrow 2\pi)=0.91\,(2S_\Lambda+1)$	$\tau_{\theta^0}/\tau_{\Xi^-}\sim 1$
5.	$R(\Sigma)/R(\Lambda)=2.5$	$\tau_\Lambda/\tau_\Sigma=11\pm 5$

Other things being equal the phase space ratio should give the observed lifetime ratios. The selection rule[1] $I=\pm\frac{1}{2}$, $I_Z=\pm\frac{1}{2}$ may apply to strange particle decays. The θ^+ cannot satisfy this selection rule whereas the θ^0, τ, Σ, Λ, and Ξ can. Therefore, we compare the lifetimes of the strange particles with the lifetime of the θ^0 rather than the θ^+. By applying the above selection rule to other strange particle decays some of the differences between the predicted and observed ratios can be resolved.

[1] G. Wentzel (to be published).

RA10. Variational Method for Field-Theoretical Scattering Problems. MICHEL BARANGER, *Carnegie Institute of Technology.*—The starting point of the method is not an interaction Hamiltonian, but the assumed exact knowledge of the structure of the physical particles in the theory. Those are, for instance, the physical nucleon for a problem of meson-nucleon scattering, or the physical meson for a problem involving meson-meson interaction. A variational principle is then set up for the scattering of these particles, in analogy with similar variational principles in first quantized quantum mechanics. It will be applied, in particular, to the problem of the scattering of a meson in a theory where a neutral meson field has an arbitrary, nonlinear interaction with a fixed, spinless nucleon. If one uses a trial wave function representing a state containing the physical nucleon plus zero or one meson, the problem is reduced to the scattering of the meson by a certain potential, which however is usually nonlocal and velocity dependent. Examples will be given. The potential vanishes, as it should, if the interaction is linear.

RA11. Interference Effects of Bremsstrahlung and Pair Production in Crystals.* H. ÜBERALL, *Cornell University.*—Estimates of an interference effect of bremsstrahlung and pair production in crystals were given recently[1] using coordinate space considerations. A quantitative analysis was done in Born approximation, working in the reciprocal lattice space. The zero-point lattice vibrations, which tend to reduce the effect, were taken into account. The bremsstrahlung spectrum is slightly enhanced at high frequencies and strongly at low ones for $\vartheta \lesssim (\alpha_{\text{screen}}/\lambda\!\!\!^{-}_C)(mc^2/E)$, ϑ = angle between direction of incidence and a line of atoms; with a copper target at 1 Bev, this amounts to an increase of the radiation of energy below 200 Mev by at least a factor 2. Pair production at 5 Bev shows a significant increase in the number of pair particles with nearly equal energy. Curves will be shown. Similar results were obtained independently by Purcell[2] using a Weizsäcker-Williams method.

* Supported in part by the Joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] F. J. Dyson and H. Überall, Phys. Rev. **99**, 604 (1955).
[2] E. M. Purcell (unpublished).

RA12. Clebsch-Gordan Coefficients for the Symmetric Groups.* E. A. CROSBIE AND M. HAMERMESH, *Argonne National Laboratory.*—Murnaghan and Gamba have given general formulas for the Clebsch-Gordan series for symmetric groups, analogous to the vector-addition theorem for the three-dimensional rotation group. We have derived formulas for the Clebsch-Gordan coefficients of the symmetric group analogous to the vector addition (Wigner) coefficients for the rotation group. The triangle relations for the rotation group are a special case of a general symmetry valid for all groups. In

addition, for the symmetric group there are symmetries related to transition to conjugate representations. The recursion formulas for the rotation group are replaced by the construction of a unitary matrix which generates the coefficients for the symmetric group on $n+1$ particles from those for n-particles. Tables of coefficients have been constructed up to $n=5$.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

RA13. The $3n-j$ Symbol: A General Approach to the Recoupling of Angular Momenta. W. T. SHARP, *Chalk River Laboratories.*—We define untwisted and twisted $3n$-j symbols as sums of certain products of Racah coefficients; the former symbol has the symmetries of a cylindrical band and the latter those of the Möbius strip. From the definitions follow orthogonality and recursion relations similar to those known for the cases $n=2$ and $n=3$ (for which the twisted symbols reduce essentially to the Racah and X-coefficients,[1] respectively) and a recoupling interpretation is always possible. For $n=4$ the untwisted and twisted symbols are the 12-j symbols of Elliott and Flowers and of Jahn, respectively. The untwisted 15-j symbol arises, for example, in the angular distribution formula for nuclear reactions in LS-coupling. For $n \geq 4$ there are other less symmetric symbols as well as the twisted and untwisted. The theory of the $3n-j$ symbol is not specific to the three-dimensional rotation group: all the general properties hold with only formal changes for an "arbitrary simply reducible" group.[2]

[1] See, for example, A. R. Edmonds, CERN Report 55-26, Geneva, 1955.
[2] E. P. Wigner, "On the matrices which reduce the Kronecker product of representations of S. R. groups," 1951 (unpublished).

FRIDAY EVENING AT 7:00

Shoreham, Terrace Room

(E. P. WIGNER presiding)

Banquet of the American Physical Society

Presentation of the Scott Medal and Premium to J. W. Beams.
After-dinner speaker: Arthur Roberts.

SATURDAY MORNING AT 9:30

Shoreham, West Ballroom

(W. W. HAVENS presiding)

Symposium on Trends in the Application of Computing Machines to Problems of Physics

S1. Problems That Can Be Attacked with Larger and Faster Machines. L. H. THOMAS, *IBM Watson Laboratories.* (30 min.)

S2. The Electronic Computer as an Experimental Tool. NICHOLAS METROPOLIS, *Los Alamos Scientific Laboratory.* (30 min.)

S3. Solving Problems of Physics with Digital Computers. A. S. HOUSEHOLDER, *Oak Ridge National Laboratory.* (30 min.)

S4. Some Techniques for the Solution of Elliptic Difference Equations on Large Scale Computers. H. H. GOLDSTINE, *Institute for Advanced Study.* (30 min.)

SATURDAY MORNING AT 9:30

NBS, Materials Testing

(T. W. BONNER presiding)

Transmutation and Nuclear Energy Levels, III

SA1. Protons from the Deuteron Bombardment of C^{13}.* JERRY B. MARION† AND GUSTAV WEBER,‡ *California Institute of Technology.*—Using an angular distribution chamber which allows the observation of reaction products at angles from 5° to 160° in 5° intervals, the ground state protons from the reaction $C^{13}(d,p)C^{14}$ have been studied as a function of energy and angle. Absolute differential and total cross sections were measured to an accuracy of 5% at 9 deuteron energies between 1 and 3 Mev. Excitation curves, obtained in this energy range at angles of 20° and 135°, exhibited a number of broad, overlapping resonances. Even at the lowest bombarding energies the angular distributions contain terms as high as $\cos^4\theta$, and become even more complicated at the higher energies. A weak maximum in the angular distribution at $\theta=25°$ occurs for $E_d \lesssim 1.7$ Mev, indicating a contribution from the stripping process. However, a considerable fraction of compound nucleus formation is apparent up to the highest bombarding energies used. The integrated angular distributions

indicate a resonance at $E_d = 1.39 \pm 0.04$ ($\Gamma \cong 0.4$ Mev), with a peak cross section of 38.0 ± 1.5 mb.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† National Science Foundation Postdoctoral Fellow.
‡ International Cooperation Administration Research Fellow.

SA2. Angular Distributions of the α Particles from the $C^{13}(He^3,\alpha)C^{12}$ Reactions at 4.5 Mev. H. D. Holmgren, R. L. Johnston, E. A. Wolicki, and E. H. Geer, *Naval Research Laboratory.*—The angular distributions of the α particles from the $C^{13}(He^3,\alpha)C^{12}$ reaction leaving the C^{12} nuclei in the ground state and the first excited state have been studied at a bombarding energy of 4.5 Mev. The yields of these two groups of α particles were measured at 16 angles extending from 5 to 155 degrees. Earlier work[1] at a bombarding energy of 2 Mev indicated that the angular distributions of these two groups were sharply peaked in the forward direction. The data at 4.5 Mev indicate that the yield of the ground-state group of α particles has a broad maximum in the region of 10 degrees with a second maximum of comparable intensity near 110 degrees and minima at about 70 and 150 degrees. The yield of the first excited state group exhibits a maximum near 50 degrees and a minimum in the region of 80 degrees, followed by a very broad maximum at large angles which is about 50% more intense than the forward maximum. The yields of the two groups when integrated over angle are about equal. The angular distributions do not have the characteristic appearance of a pickup process nor do they resemble the angular distributions expected from compound nucleus formation.

[1] H. D. Holmgren, Bull. Am. Phys. Soc. Series II, 1, No. 1, 21 (1956).

SA3. Angular Distributions of Neutrons from the $C^{13}(\alpha,n)O^{16}$ Reaction.* J. P. Schiffer, Alfred A. Kraus, Jr., and J. R. Risser, *The Rice Institute.*—The Rice Institute 6-Mev Van de Graaff generator has been used to study the angular distribution of neutrons from the $C^{13}(\alpha,n)O^{16}$ reaction leaving O^{16} in its ground state. A modified long counter with angular resolution ranging from 3° to 10° was used. Angular momentum assignments for some of the resonances reported by Schiffer, Bonner, Kraus, and Marion[1] corresponding to states in O^{17} have been made. Consistent assignments are 3/2 at α-particle energy of 2.42 Mev, 3/2 at 2.83, 5/2 at 2.69, 3/2 at 3.09, 3/2 at 3.33, 7/2 at 4.13, 7/2 at 4.42, 9/2 at 4.63, and 7/2 at 4.75. Interference effects make the assignment of some of the broader resonances ambiguous. Some relative parity assignments can be made on the basis of the interference effects.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Schiffer, Bonner, Kraus, and Marion, Bull. Am. Phys. Soc. Series II, 1, No. 1, 20 (1956).

SA4. Angular Distributions of Ground-State Protons from $C^{13}(He^3,p)N^{15}$. E. H. Geer, H. D. Holmgren, R. L. Johnston, and E. A. Wolicki, *Naval Research Laboratory.*—Using the Naval Research Laboratory 5-Mv Van de Graaff generator, we have bombarded thin isotopically enriched C^{13} targets with 4.5-Mev He^3 particles. The yield of the proton group which leaves the product nucleus N^{15} in its ground state was studied at ten degree intervals from 10 to 155 degrees. Aluminum foils stopped the less energetic proton groups. The resulting angular distribution is peaked in both the forward and backward directions, the yield at 10 degrees being about six times that at 100 degrees. The rise at large angles is less pronounced. The same reaction has been studied at 2.0 Mev, using the Naval Research Laboratory 2-Mv Van de Graaff generator, and these results will also be presented.

SA5. Excitation Functions and Angular Distributions of the $C^{13}(\alpha,n)$ Reaction. R. B. Walton and J. D. Clement, *University of Wisconsin.**—A study of the $C^{13}(\alpha,n)$ reaction has been continued. Excitation functions at 0°, 29°, 90°, 146° have been measured over the energy interval from 2.02 Mev to 3.52 Mev. The forward yield measurement was extended down to 0.83 Mev. Resonances were observed at α-particle energies of 1.070 Mev (width <18 kev), 1.348 (<20), 1.603 (<15), 1.746 (30), 2.08 (150), 2.25 (80), 2.44 (75), 2.612 (20), 2.688 (<15), 2.775 (20), 2.816 (<15), 3.09 (90), 3.33 (130), and 3.42 (70). The positions of the resonances are in agreement with those obtained by other workers[1] at energies where the data overlap. The reaction cross section for the emission of neutrons in the forward direction varied from about 0.03 millibarn per steradian at the lowest energy to about 50 millibarns per steradian at the peak of the highest resonance. Angular distributions were measured at several of the resonances and in the region from 2.88 to 3.03 Mev. Spin assignments for four levels in the compound nucleus O^{17} will be discussed.

* Work supported in part by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.
[1] Jones and Wilkinson, Proc. Phys. Soc. (London) **A66**, 1176 (1953); Schiffer, Bonner, Kraus, and Marion, Bull. Am. Phys. Soc. Series II, 1, No. 1, 20 (1956).

SA6. Nuclear Resonance Fluorescence in O^{16}.* C. P. Swann and F. R. Metzger, *Bartol Research Foundation.*—Using the Bartol-ONR Van de Graaff generator and the reaction $F^{19}(p,\alpha)O^{16*}$ as the gamma-ray source, nuclear resonance fluorescence in O^{16} has been observed. A thick target of CaF_2 was bombarded with 2 μa of 3-Mev protons to give a source strength of about 10^9 gamma rays per second. A ring geometry similar to the one employed in previous resonance fluorescence experiments[1] was used. Water and benzene scatterers were compared and the difference in the counting rates was attributed to resonance fluorescence in oxygen. Great care was taken to eliminate all neutrons since their presence tended to conceal the effect. Of the first four levels in O^{16} only the 6.91-Mev and 7.12-Mev states can be responsible for the resonance effect. The angular distribution of the resonance radiation shows indeed that both of these levels participate. The reduction of the resonance effect by means of a water absorber placed between the gamma-ray source and the scatterer indicates that the lifetimes of these two levels are the same to within a factor of three. Preliminary measurements give lifetimes between 10^{-14} and 10^{-15} second.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] See, e.g., Franz R. Metzger, Phys. Rev. **101**, 286 (1956).

SA7. States in O^{16} from Gamma Rays from $N^{15}+P$ Reactions. R. R. Carlson and S. Bashkin, *State University of Iowa.**—The yield of 4.43-Mev gamma rays from the reaction $N^{15}(P,\alpha\gamma)C^{12}$ has been measured with thin, nitrogen gas targets enriched to 61% in N^{15}, for proton energies between 800 kev and 3800 kev. The $N^{15}(P,\gamma)O^{16}$ yield has also been measured for proton energies between 800 kev and 3300 kev. Previously known[1,2] resonances for the reaction $N^{15}(P,\alpha\gamma)C^{12}$ were confirmed at 898 kev, 1050 kev, 1220 kev, and 1660 kev, but the width of the 1660-kev state was found to be (65 ± 10) kev instead of the previously reported[2] $\Gamma \approx 150$ kev. New resonances were located at (1995 ± 20) kev, $\Gamma = (25 \pm 5)$ kev, (3000 ± 30) kev, $\Gamma = (45 \pm 10)$ kev; (3300 ± 35) kev, $\Gamma = (75 \pm 15)$ kev; and (3520 ± 40) kev, $\Gamma = (100 \pm 25)$ kev. The three highest resonances are superimposed on another at (3350 ± 50) kev, $\Gamma = 700$ kev. Angular distributions have been measured from −135° to +135° in 15° steps for the 1220 kev and all higher resonances, and at 2750 kev, where the tail of the 3350-kev resonance is distinct from the others. Agreement is found with prior work[1] at 1220 kev and 1660 kev. The broad state may contribute appreciably to the cross section at stellar energies. The capture radiation shows only the known[1] resonance at 1050 kev, $\Gamma = (125 \pm 25)$ kev.

* Supported in part by U. S. Atomic Energy Commission.
[1] Schardt, Fowler, and Lauritsen, Phys. Rev. **86**, 527 (1952).
[2] A. A. Kraus, Phys. Rev. **94**, 975 (1954).

SA8. States in O^{16} from Alpha Particles from the Reaction $N^{15}(P,\alpha)C^{12}$. J. A. JACOBS, S. BASHKIN, AND R. R. CARLSON, *State University of Iowa.**—Thin, nitrogen gas targets, enriched to 61% in N^{15}, were bombarded with protons between 950 kev and 3800 kev. Long-range alphas from the reaction $N^{15}(P,\alpha)C^{12}$ were detected in a proportional counter subtending a small solid angle at 132° to the incident beam. Short-range alphas were absorbed in mica in front of the counter. Scattered protons were distinguished from long-range alphas by pulse-height analysis. Strong resonances were found at 1050 kev and 1220 kev, confirming previous work.[1] Weak resonances appeared at (2990±20) kev and (3500±30) kev; these lie on top of a broad resonance. Resonances are not seen at 1660 kev, 1995 kev, or 3300 kev where they appear in the reaction $N^{15}(P,\alpha\gamma)C^{12}$ (see preceding abstract). Resonances in the $N^{15}(P,\alpha)C^{12}$ yield correspond only to (even J, even π) or (odd J, odd π) states in O^{16}. Resonances observed in $N^{15}(P,\alpha\gamma)C^{12}$ but not in $N^{15}(P,\alpha)C^{12}$ are attributed to (odd J, even π) or (even J, odd π) states in O^{16}.

* Supported in part by U. S. Atomic Energy Commission.
[1] Schardt, Fowler, and Lauritsen, Phys. Rev. **86**, 527 (1952).

SA9. States in O^{15} and O^{16} from Elastic Scattering of Protons by N^{14} and N^{15}. S. BASHKIN, R. R. CARLSON, AND J. A. JACOBS, *State University of Iowa.**—Protons elastically scattered from a thin, nitrogen gas target, enriched to 61% in N^{15}, have been observed in a proportional counter subtending a small solid angle at 132° to the incident beam. Pulse-height analysis separated the protons from long-range alphas from $N^{15}(P,\alpha)C^{12}$, and a mica foil absorbed the short-range alphas from $N^{15}(P,\alpha\gamma)C^{12}$ before they entered the counter. Measurements were made for proton energies between 950 kev and 3960 kev. Various anomalies which appeared may be qualitatively identified with states in O^{15} and O^{16}. The general trend of the yield curve is a decreasing function of proton energy, but the rate of fall is slower than calculated from Rutherford scattering. Measurements on a natural nitrogen gas target show that a sharp peak at a proton energy of (3200±80) kev is associated with scattering from N^{14}, while other structure near 3000-kev bombarding energy is attributed to scattering from N^{15}. A large peak, of as yet undetermined origin, appears at (3920±40) kev.

* Supported in part by the U. S. Atomic Energy Commission.

SA10. Excited States in O^{16} from $N^{15}(p,\alpha\gamma)C^{12}$.* L. LIDOFSKY, K. JONES, R. BENT, J. WEIL, T. KRUSE, M. BARDON, AND W. W. HAVENS, JR., *Columbia University.*—Highly excited states of O^{16} have been studied by the $N^{15}(p,\alpha\gamma)C^{12}$ reaction using the Columbia Van de Graaff.[1] A thin, enriched (95%) N^{15}[2] gas target was bombarded with protons of $E_p=2.65$ to 5.25 Mev and the 4.43-Mev gamma ray from C^{12} was detected using a 3 in.×3 in. NaI crystal and a multichannel analyzer. Resonances were observed at $E_p=3.00$, 3.29, 3.51, 3.92, and 4.61 Mev with widths of 60, 60, 95, 30, and 25 kv, respectively, superimposed on a generally rising yield. These resonances correspond to states in O^{16} with excitation energies 14.92, 15.20, 15.41, 15.79, and 16.43 Mev. The first three resonances agree with those observed by Carlson and Bashkin.[3] Additional resonances for 4.43-Mev gamma radiation observed at $E_p=5.02$ and 5.14 Mev have not as yet been definitely assigned. The yield of $N^{15}(p,\gamma)O^{16}$ has also been observed and will be reported. These studies are being continued to higher energies.

* This work was partially supported by the U. S. Atomic Energy Commission.
[1] High Voltage Engineering Corporation, Cambridge, Massachusetts.
[2] W. Spindell and T. I. Taylor, J. Chem. Phys. **23**, 1318 (1955).
[3] R. R. Carlson and S. Bashkin, Phys. Rev. **100**, 1254(A) (1955); S. Bashkin (private communication).

SA11. Spin and Parity of the First Excited State of Na^{23}. R. W. KRONE AND W. G. READ, *University of Kansas.*—The angular distribution of the gamma rays resulting from the $Na^{23}(p,p'\gamma)Na^{23}$ reaction has been measured for proton bombarding energy $E_p=1.228$ Mev. At this bombarding energy a well-known isolated resonance is excited in the Mg^{24} compound nucleus which decays by the p_0 and α_0 channels as well as by the above inelastic scattering process. The spin and parity of this resonance has been reported as $1-$ from two different experiments: First by Stelson[1] from the angular distribution of the alpha particles produced by the $Na^{23}(p,\alpha)Ne^{20}$ reaction, and just recently by Baumann *et al.*[2] from the elastic scattering of protons by Na^{23}. The angular distribution of the gamma rays was found to be $W(\theta)=P_0-0.074P_2$. The anisotropy exhibited rules out an assignment of $J=\frac{1}{2}$ for the first excited state of Na^{23}. Assignments of $3/2\pm$ or $5/2\pm$ can each be made to fit the data under special conditions. If one makes, however, the same assumptions Stelson had to make to fit the ground-state alpha distribution, i.e., that the compound state is formed predominantly with channel spin $S=2$ as well as with a large admixture of f-wave protons, the assignment $5/2+$ predicted by the shell model gives the best fit of the data.

[1] P. H. Stelson, Phys. Rev. **96**, 1584 (1954).
[2] Baumann, Prosser, and Krone, Phys. Rev. **100**, 1244 (1955).

SA12. $Al^{27}(d,p)Al^{28}$ Stripping Analysis. H. A. ENGE, W. W. BUECHNER, A. SPERDUTO, AND M. MAZARI, *MIT.**—Angular distribution measurements have been made on proton groups from the $Al^{27}(d,p)Al^{28}$ reaction with the MIT–ONR broad-range magnetic spectrograph. Deuteron energy: 6.0 Mev; reaction angle: 5 to 60 degrees. Of the angular distributions for the twenty-two lowest states[1] thus far plotted and analyzed, eleven show definite contributions from the stripping process. These states and the corresponding orbital angular momentum quantum numbers for the captured neutron are listed below:

State (Mev):	Ground	0.031	1.017	2.143	2.663	3.294
$l_n=$	0	0	2,0	0	2	0
State (Mev):		3.347	3.461	3.591	3.669	3.704
$l_n=$		0	1	1	0	0

Most of the proton groups from the other eleven states are relatively weak and, within the limits of error, fairly isotropic. The possibility of $l_n=2$ or 3 stripping contributions in some of these states is being looked into.

* This work has been supported in part by the joint program of the U. S. Atomic Energy Commission and the Office of Naval Research.
[1] Buechner, Mazari, and Sperduto, Phys. Rev. **101**, 188 (1956).

SA13. Isotopic Spin-Selection Rule Violation in $Si^{28}(d,\alpha)Al^{26}$. CORNELIUS P. BROWNE, *MIT.**—The reaction $Si^{28}(d,\alpha)Al^{26}$ was investigated in a search for an alpha group leading to the state in Al^{26} at 0.23 Mev known from gamma-ray measurements.[1] Failure to observe this group at 90 degrees indicated that this is the expected $T=1$ state.[2] Alpha groups have now been measured at 30 degrees with various bombarding energies and from 15 to 130 degrees at 7.03 Mev. The MIT broad-range spectrograph was used. A group corresponding to a state at 0.228±0.005 Mev was observed in addition to the previously reported group.[3] Identification was based on energy shift, angle shift, and change of isotopic abundance. The yields of this state, the ground state, and the 0.418-Mev state were measured at 250-kev intervals from 5.5 to 7.5 Mev at 30 degrees. Between 6.25 and 7.03 Mev, the ground-state yield was measured at 25-kev intervals; at least seven resonances were observed. The intensity of the forbidden group varies by a factor of 10. The ratio of this group to the ground-state group varies from 2 to 65%. At 7.03 Mev, the ratio decreases from 62% at 15 degrees to 12% at 60 degrees. The group is not seen at greater angles.

* This work has been supported in part by the joint program of the U. S. Atomic Energy Commission and the Office of Naval Research.
[1] Kluyver, van der Leun, and Endt, Physica **20**, 1287 (1954).
[2] C. P. Browne, Phys. Rev. **95**, 860 (1954).

SA14. Elastic Scattering of Protons from S^{32}.* J. W. OLNESS, W. HAEBERLI, AND H. W. LEWIS, *Duke University.*—

The differential cross section for the elastic scattering of protons from S^{32} has been measured for proton energies between 1.8 and 4.0 Mev and laboratory angles of 62.2°, 90.0°, 123.8°, 139.6°, and 167.2°. Protons with an energy spread of 0.05 to 0.1% entered a differentially pumped gas scattering chamber containing H_2S gas at pressures of 0.1 to 0.6 cm Hg. A CsI scintillator 0.03 cm thick served as the detector of scattered protons. Eleven resonances with the following resonant energies (E_{lab}, Mev) and total widths (kev) were observed: 1.900 (8.5), 2.575 ($\leq$5), 2.30 (52), 2.810 ($\sim$6), 2.902 ($\leq$5), 2.917 ($\leq$5), 3.092 ($\leq$4), 3.194 ($\leq$4), 3.265 (32), 3.381($\leq$4), 3.718 ($\leq$4). In addition, the 167.2° cross section shows a broad dip, ($\sim$300 kev wide) near 2.9 Mev, and at higher energies, a peak roughly 300 kev wide which seems to be due to two overlapping resonances at about 3.5 Mev. An analysis of these data has been started. Preliminary assignments of J^π for excited states of Cl^{33} are: $\frac{3}{2}^-$ for the state corresponding to $E_p=1.900$; $\frac{1}{2}^-$ ($E_p=2.30$ Mev); $\frac{3}{2}^-$ ($E_p=2.810$ Mev); $\frac{1}{2}^+$ ($E_p=3.265$). The first two assignments agree with the earlier work reported by Gove and Ferguson.[1]

* This work was supported in part by the U. S. Atomic Energy Commission.
[1] A. J. Ferguson and H. E. Gove, Phys. Rev. **91**, 439(A) (1953).

SA15. Inelastic Scattering of Protons from S^{32}.* H. W. Lewis, J. W. Olness, and W. Haeberli, *Duke University.*—The gamma-ray yield from thin (3 to 30 kev) evaporated SbS_3 targets bombarded with protons of 0.05 to 0.1% energy spread has been studied for proton energies between 2.7 and 3.8 Mev with an NaI detector. Gamma rays of energy 2.2 Mev, attributed to inelastic scattering to the first excited state of S^{32} were found to be resonant at $E_p=2.810$, 2.902, 2.917, 3.094, 3.195, 3.379, and 3.716 Mev. The shape of the rise in yield near the resonances, observed with a 30-kev target indicates a width <2 kev for all resonances above 3 Mev. The angular distributions of the gamma rays were determined for the four resonances above 3 Mev, and were found to be anisotropic. In addition, inelastically scattered protons were observed in a gas scattering chamber[1] at $E_p=3.380$ and 3.719 Mev. The angular distribution of inelastically scattered protons peaks at 90° for $E_p=3.719$ Mev and has a minimum at 90° for $E_p=3.380$. All distributions can be fitted by a sum of even Legendre polynomials of degree four and less.

* This work was supported in part by the U. S. Atomic Energy Commission.
[1] See abstract SA14, this issue.

Saturday Morning at 9:30

Sheraton Park, Grand Ballroom

(D. L. Dexter presiding)

Solid State Physics, II, Including Alkali Halides

T1. Effect of Halide Coactivators on Absorption and Emission Phenomena in Zinc Sulfide Phosphors with Copper Activator. R. E. Shrader, S. Larach, and I. J. Hegyi, *RCA Laboratories.*—The "coactivator" used in the synthesis of phosphors has variously carried the role of "flux," "charge-compensating agent," and "trapping-agent." It is now apparent that variation in the nature of the halide coactivator used in the synthesis of electroluminescent ZnS:Cu produces definite effects not only in the electroluminescence phenomenon, but also in the photoluminescence and the cathodoluminescence. Variations in the reflection spectra are also found.

T2. *F*-Band Oscillator Strength in NaCl and KCl.*† R. H. Silsbee,‡ *Harvard University.*—The oscillator strength of the *F*-band absorption in KCl and NaCl has been obtained by a new method. The concentration of centers is determined by the measurement of the intensity of the paramagnetic resonance absorption of the *F*-centers. This method avoids certain of the assumptions made in previous determinations, and is applicable to either x-irradiated or additively colored crystals. The results of this work give a value of $f=0.85$ for KCl and $f=0.87$ for NaCl, making the usual assumptions of a Lorentz local field and a Lorentzian line shape for the optical *F*-band absorption. The effects of these assumptions on the *f*-value will be noted and the results will be compared with those of other workers. The accuracy of these values is estimated to be $\pm 5\%$.

* Part of thesis submitted to Harvard University (January, 1956).
† Supported by the Office of Naval Research.
‡ Present address: Oak Ridge National Laboratory.

T3. Rate of Formation of *F*-Centers in Partially X-Ray Irradiated Alkali Halide Crystals.* Lan-Ying Lin and M. E. Caspari, *University of Pennsylvania.*—The over-all relative linear expansion of partially x-ray irradiated potassium and sodium chloride crystals was found to be proportional to the average *F*-center concentration in the irradiated portion, but not to the *F*-center concentration averaged over the whole crystal.[1] Further experiments have shown that the rate of formation of *F*-centers in partially x-ray irradiated crystals is directly proportional to the fraction of the volume which is exposed to the irradiation and that the *F*-center concentration after a certain period of irradiation in a previously uncolored part is greatly increased by first irradiating an adjacent part. These experiments indicate the presence of a large number of vacancies in the nonirradiated portion of the crystal. The diffusion of vacancies in alkali halide crystals is not large enough to account for this rapid transfer of vacancies, but slip processes[2] may possibly explain the effects.

* Supported by the U. S. Air Force through the Office of Scientific Research of the Air Research and Development Command.
[1] Lan-Ying Lin and B. R. Russell, Phys. Rev. **99**, 657(A) (1955).
[2] Smith, Levio, and Smoluchowski, Phys. Rev. **101**, 37 (1956).

T4. Enhanced X-Ray-Induced *V*-Bands in Polycrystalline Alkali Halides. Herbert N. Hersh, *Zenith Radio Corporation.*—Transparent polycrystalline pellets of potassium iodide and bromide have been x-rayed and the resulting spectra in the ultraviolet compared with those of the corresponding x-irradiated single crystals and with single crystals containing a stoichiometric excess of the halogen. Enhanced growth rates of some of the *V*-bands are observed. In the case of KI there results a V_2, V_3 doublet which is stable, and is practically identical with the bands found by Mollwo in KI with excess iodine; only an unresolvable broad band occurs in the same spectral region when a single crystal is similarly irradiated. The results furnish experimental verification of the identity between some of the *V*-bands induced by x-rays and by reaction at high temperature of the alkali halide and corresponding halogen. Further, it is indicated that the center (or centers)

associated with these bands in KI and KBr can reside on or near external surfaces.

T5. Self-Diffusion of Sodium and Conductivity in Sodium Chloride Crystals.* J. O. THOMSON,† *University of Illinois.*—Na^{24} tracer diffusion measurements and conductivity measurements have been made on single crystals of NaCl containing small amounts of $CaCl_2$ (6 and 20×10^{-4} mole fraction). The measurements were made in the temperature range from 240°C to 590°C. The self-diffusion coefficient of the sodium ion was obtained from the tracer diffusion coefficient by application of the Bardeen-Herring correlation factor.[1] The ratio (σ/D) of the conductivity to the self-diffusion coefficient satisfies the Einstein-Nernst relation much better than data obtained from $NaCl-CdCl_2$ crystals.[2] This result may not be due to a small binding energy of the calcium ion-positive ion vacancy complex, because the ratio, (σ/D), and the conductivity, σ, do not depend upon the temperature and concentration of calcium in the manner predicted by association theory.[3]

* Assisted by the Office of Scientific Research.
† Corning Glass Company Fellow.
[1] J. Bardeen and C. Herring, *Imperfections in Nearly Perfect Crystals* (John Wiley and Sons, Inc., New York, 1952).
[2] J. F. Aschner, thesis, University of Illinois, 1954.
[3] A. B. Lidiard, Phys. Rev. **94**, 29 (1954).

T6. Optical Absorption in Irradiated Corning Silica. C. M. NELSON AND J. H. CRAWFORD, JR., *Oak Ridge National Laboratory.*—Exposure of Corning silica to 250-kv x-rays, Co^{60} γ rays, and fast neutrons produces an absorption band at 2120 A. Fast neutrons also introduce a poorly resolved band at 2750 A. Negligible visible coloration is produced. The neutron results agree with observations of Levy.[1] The 2120 A band is partially bleached by ultraviolet radiation but heating at 700°C is required for complete decoloration. Curves of extinction coefficient ϵ at 2120 A *vs* exposure indicate saturation by a first-order law whereas coloration by neutrons proceeds by a more complex process and attains a saturation absorption ϵ_∞ which is ~25 times as great as produced by photons. ϵ_∞ produced by γ rays varies from one batch of Corning silica to another. Pretreatment of the specimens also has an appreciable effect on ϵ_∞, e.g., previous annealing (700°C and 1000°C) reduces ϵ_∞ while prior fast neutron bombardment followed by thermal bleaching causes a sharp initial rise in ϵ and enhances ϵ_∞. This behavior suggests that the 2120 A band in fused silica is connected with ruptured Si−O bonds or free radicals. Coloration by photons would then be enhanced by localized strains which would render more stable those bonds ruptured by ionization effects.

[1] P. W. Levy, J. Chem. Phys. **23**, 764 (1955).

T7. Relaxation in Glasses Subjected to Hydrostatic Pressure. C. WEIR, S. SPINNER, I. MALITSON, AND W. RODNEY, *National Bureau of Standards.*—Studies were made of index of refraction at 1 atmos and 25°C of glasses subjected to hydrostatic pressures of 9000 atmos at 21°C. Immediately following the removal of pressure the index is higher than the original value. The increase in index $(n-n_0)/n_0$ is of the order of a few parts per million and depends on the composition and initial state of the glass. This index decays with time ultimately reaching the initial value n_0. The over-all process is decidedly nonsymmetrical with the time required for recovery being much longer than the time under pressure. Fused silica showed no change in index within an error of a few parts in 10^7. Correspondingly sensitive measurements of other properties, such as volume changes, should give more information concerning the processes involved.

T8. Effective Mass in Narrow Impurity Bands. FRANK STERN, *U. S. Naval Ordnance Laboratory.*—The hydrogenic picture of isolated impurities in a semiconductor can be extended to the case of interacting impurities,[1,2] and predicts a band whose width increases with increasing impurity concentration. For sufficiently low donor concentration, N_D, the impurity band will be narrow and well separated from the conduction band at low temperatures. The effective mass in the impurity band, m_i, is of interest in such a case because of its relevance to the mobility of impurity band electrons. Using a method previously described,[2] we find

x_s	2.50	3.21	3.79	4.28	4.73	5.16
(m_i/m_c)	1.09	1.35	1.9$_2$	2.8$_6$	4.3	7.4

where $x_s^{-3}=6.2\times10^{-25}(\kappa m/m_c)^3N_D$. The free electron mass and the effective mass at the bottom of the conduction band in pure material are given, respectively, by m and m_c; κ is the dielectric constant. These values of (m_i/m_c) are slightly smaller than those obtained by Baltensperger[1] by a different method. For large values of x_s we find the following: $(m_i/m_c)=3(2x_s)^{-4}e^{2x_s}$. This holds within about 10% for $x_s>4$.

[1] W. Baltensperger, Phil. Mag. **44**, 1355 (1953).
[2] F. Stern and R. M. Talley, Phys. Rev. **100**, 1638 (1955).

T9. The Anisotropy of the Hot Electron Problem in Semiconductors with Spheroidal Energy Surfaces.* L. GOLD, *Lincoln Laboratory.*—The directional energy gain for electrons in germanium and silicon has been determined as a means of deducing the anisotropy of electrical breakdown. Treating each of the ellipsoidal energy surfaces individually with the restriction of isotropic scattering, leads to the directions [211] and [110] in germanium for maximal energy gain; the corresponding directions in silicon are [100] and [110]. Viewed from the theory of breakdown based upon the energy balance of carrier energy gain *vs* energy loss to the lattice, these directions should be the easy ones for breakdown. The anisotropy of the effect does not appear to be very large. Thus, in germanium, the relative accelerative masses along the easy, [211], [110], directions and the hard [100] direction is about 0.7. The effect of anisotropic intra-valley scattering has been examined for germanium. Assuming a scattering tensor of the form (τ_l,τ_t,τ_t) where τ_l and τ_t are the longitudinal and transverse scattering times, it turns out that for the limits $\tau_l/\tau_t\to\infty$ and 0, the presumed directions for the easy and hard directions of breakdown lie along the [100] and [111] directions, respectively. Shibuya has found the anisotropy of the collective behavior in the nonlinear region of Ohm's law.

* The research reported in this document was supported jointly by the U. S. Army, the U. S. Navy, and the U. S. Air Force under contract with the Massachusetts Institute of Technology.

SATURDAY MORNING AT 9:30

Shoreham, Main Ballroom

(N. F. RAMSEY presiding)

Radio-Frequency Spectroscopy

TA1. Effect of Paramagnetic Gases on the Paramagnetic Resonance Absorption in Charred Sucrose. L. S. SINGER AND W. J. SPRY, *National Carbon Research Laboratories.*—Paramagnetic resonance measurements at a frequency of 9300 Mc/sec have been made on sucrose which was heated in N_2 or A at 670°C for ½ hr. The unground char shows no absorp-

tion; however, the same samples when ground, exhibit Lorentz-shaped resonance lines, the widths and maximum intensities of which are functions of the pressure of O_2 and NO but independent of the pressure of N_2, A, and Cl_2. The full width of the resonance at $\frac{1}{2}$ maximum absorption for the ground char either in an inert atmosphere or at zero pressure is 90 gauss. At an O_2 pressure of 2 cm of Hg, the corresponding line width is 250 gauss. The total integrated intensities, within an experimental uncertainty of 15%, are independent of the nature or pressure of the gas and correspond to electron concentrations of about 1 electron per 500 carbon atoms. If it is assumed that the electron spins are associated with the surface of the char, a picture consistent with the observations depicts the paramagnetic gas simply as providing an effective mechanism for the transfer of energy from the spin system to the gas.

TA2. Field-Gradient Calculations in the Hydrogen Molecule.* T. P. Das, *Institute of Nuclear Physics, Calcutta* (introduced by R. Bersohn).—The field gradient q at the position of the nuclei in the hydrogen molecule has been calculated using two-center integrals,[1] for a number of different wave functions that have been proposed for the H_2 molecule. The following conclusions are drawn. (a) Even the simplest molecular orbital or valence-bond function composed of unshielded atomic hydrogen wave functions does not give an error of more than 33% from Newell's[2] value. (b) The effect of shielding, manifested by using either Coulson's LCAOMO or Wang, VB functions, is very important. (c) In the case of the simple functions, there is a concurrent improvement in q with improvement in energy. (d) The contribution of q from the electrons is underestimated with all the simple VB and MO functions, but the MO theory gives a better value, probably because it underrates the interelectronic repulsion. The calculated q's will be presented and details will be given.

* This work was supported by the U. S. Atomic Energy Commission.
[1] Barnett and Coulson, Phil. Trans. Roy. Soc. **A243**, 221 (1951).
[2] G. F. Newell, Phys. Rev. **78**, 711 (1950).

TA3. Na^{23} Quadrupole Coupling Constants of Sodium Nitrate and Sodium Chlorate. R. Bersohn, *Cornell University.*—In an ionic crystal the electric field gradient at the nucleus must have an external origin because the unpolarized Na^+ ion is in the ^1S-state. We can write

$$\frac{eqQ_{23}}{h}=\frac{e^2}{ha^3}(1-\gamma_\infty)Q_{23}(c_1+c_2z),$$

where a is the unit cell length, $1-\gamma_\infty$ takes into account the quadrupole polarization of the ion, Q is the nuclear quadrupole moment. The XO_3^- ion is idealized as a system of four point charges, a charge ze at the X-atom and $(-(1+z)e/3)$ at each oxygen atom. c_1 is 5.046, −11.13 and c_2 is −6.908, −4.955 for $NaNO_3$ and $NaClO_3$, respectively. Taking the ratio of the two coupling constants ±334 and ±801 kc/sec, respectively, yields $z_{Cl}=\pm(0.479-3.73z_N)$. Using the + sign and letting $z_{Cl}=z_N=0.101$, we find that $Q_{23}(1-\gamma_\infty)=0.556$ barns. Recently Sternheimer, Foley, Das, and Bersohn obtained theoretically the value 5.5 for $1-\gamma_\infty$. Using this number, $Q_{23}=0.1$ barn which should help to resolve the ambiguity in the atomic beam determination of this quantity. We are grateful to the staff of the AEC UNIVAC for calculating c_1 and c_2.

TA4. Chlorine Nuclear Quadrupole Resonance in Tungsten Hexachloride.* W. S. Koski and R. P. Hamlen, *The Johns Hopkins University.*—The pure nuclear quadrupole resonance frequency has been measured for Cl^{35} and Cl^{37} in tungsten hexachloride using a self-quenched super-regenerative oscillator. At 23°C the Cl^{35} resonance occurs at 10.525 Mcps, and a positive temperature coefficient was observed. Using the usual assumption of 18% s-hybridization for the p-bonding orbital of a chlorine in an appreciably ionic bond, this resonance frequency corresponds to an ionic character of approximately 80%.

* Research supported by the U. S. Air Force, through the Office of Scientific Research of the Air Research and Development Command.

TA5. Quadrupole Resonances and Electron Distribution.* P. A. Casabella and P. J. Bray, *Brown University.*—The measured pure quadrupole resonances of Br^{79} in O-dibromobenzene and hexabromobenzene are 282.574, 282.455 Mcps and 255.283, 254.792 Mcps, respectively, at 77°K. Two resonances are probably unobserved[1] as yet in O-dibromobenzene. The third resonance[1] in hexabromobenzene is resolved at room temperature. The known frequencies in seven multibromobenzenes can now be plotted as a function of the number of bromines on the ring as have the multichlorobenzenes.[1] The Br^{79} frequency increases by 6 to 10 Mcps when a neighboring proton is replaced by another bromine atom. The double bond character of the Br−C bond *increases* in such a case as shown[2] by the asymmetry parameters of 0.041±0.005 and 0.085±0.015, respectively, in p-diiodobenzene and O-diiodobenzene[1]: [O-diiodobenzene: $f=286.923$, 286.285, 285.531, 284.036; 566.330, 566.080, 565.200, 564.540 Mcps. p-diiodobenzene: $f=280.147$; 559.104 Mcps 77°K]. This would *decrease*[2] the resonance frequency. The large observed *increase* is owing to inductive effects.

* Research supported by a grant from the Research Corporation.
[1] Bray, Barnes, and Bersohn, "Pure quadrupole resonances in multichlorobenzenes," J. Chem. Phys. (to be published).
[2] R. Bersohn, J. Chem. Phys. **22**, 2078 (1954).

TA6. Effect of Various Impurities on the Quadrupole Spectrum of Cl^{35}. O. Kraus, R. E. Michel, and W. H. Tanttila, *Michigan State University.*—Several investigators have described[1–3] the effect of impurities on quadrupole resonance of Cl^{35} occurring in organic compounds that are solid at room temperature. The present experiments, performed at liquid-nitrogen temperature on organic compounds which are liquids at room temperature exhibit effects more general than previously reported.[1,2] The effect of impurities on various chlorine-substituted methanes as well as 1,2 dichloroethane, T-butyl chloride, and chlorobenzene has been investigated. Benzene, hexane, methyl alcohol as well as the preceding compounds have been used as impurities. The effectiveness of the impurities in diminishing the intensity of the quadrupole resonance was greater for the methyl derivatives than for 1,2-dichloroethane. The effect of the impurities in T-butyl chloride was to enhance the intensity of the quadrupole resonance at low concentrations. Benzene as an impurity is extremely effective in diminishing the quadrupole resonance in chlorobenzene, and progressively less effective in dichloromethane, chloroform and 1,2-dichloroethane. Contrary to results reported elsewhere on other compounds,[1] the integrated intensity falls off with an increase in impurity although the resonance shows appreciable broadening. Curves which show the effect of impurity concentration on the intensity of quadrupole resonance will be presented.

[1] S. L. Segel and B. C. Lutz, Phys. Rev. **98**, 1183 (1955).
[2] C. Dean, J. Chem. Phys. **23**, 1734 (1955).
[3] R. D. Spence (unpublished).

TA7. Paramagnetic Resonance of Organic Free Radicals at Millimeter Wave Frequencies.* Arend van Roggen, Lien van Roggen, and Walter Gordy, *Duke University.*—A sensitive paramagnetic resonance spectrometer employing a superheterodyne receiver has been constructed for the 3 to 4 mm wave region. The radicals p-anisyl nitrogen oxide (A) and 2-(phenyl nitrogen oxide)-2-methyl pentane-4-one-oxime-N-phenyl ether (B), originally observed as powders at 24 kMc,[1] have been studied at 36 kMc and 75 kMc as single crystals and in liquid and frozen solutions. With reference to the cylindrical axis of (A) in the magnetic field, the values $g=2.0095$ and $g=2.0035$ were found. Crystals of (B)

do not have exactly cylindrical symmetry. For it the g-values 2.0080, 2.0064, and 2.0043 for three orientations differing by 90° were observed. The anisotropy in g of either crystal is too large to result from diamagnetism of the benzene rings and probably arises from spin-orbit coupling. Triplet hyperfine structures were observed for both radicals in dilute benzene solutions with a spread of respectively 25 and 27 gauss. For both, we conclude that the odd electron is mainly located on the NO group. Only broad, unresolved resonances are observed for the frozen solutions. Evidently the hyperfine structure is smeared out by the anisotropic coupling terms which are not canceled out by tumbling motions as they are in liquid solutions.

* Supported by the Office of Ordnance Research, U. S. Army.
[1] Holden, Kittel, Merritt, and Yager, Phys. Rev. **75**, 1614 (1949); **77**, 147 (1950).

TA8. Crystallinity of Polyethylene by Nuclear Resonance. R. L. COLLINS, *Phillips Petroleum Company.*—The nuclear resonance method of measuring the absolute crystallinity of polyethylene has been described by Wilson and Pake.[1] The superimposed wide and narrow proton lines in polyethylene were assigned to the crystalline and amorphous phases. Since it is not obvious that this assignment of crystallinity based on correlation time is equivalent to that based on order, a comparison of nuclear resonance and x-ray diffraction crystallinities[2] has been made for a number of polyethylenes having room-temperature crystallinities ranging from 59 to 93%. The reproducibility of the x-ray values is best at low crystallinities, and the reproducibility of the nuclear resonance values is best at high crystallinities. The average difference between the nuclear resonance and x-ray crystallinities is 1.8%, which is within the uncertainty of the relative x-ray scattering efficiencies of crystalline and amorphous polyethylene. The nuclear resonance method appears to offer definite advantages of reproducibility, ease of sampling, and insensitivity to orientation.

[1] C. W. Wilson and G. E. Pake, J. Polymer Sci. **10**, 503 (1953).
[2] The x-ray diffraction measurements were made by Dr. R. Q. Gregg of this laboratory following essentially the method described by Matthews, Peiser, and Richards, Acta. Cryst. **2**, 85 (1949).

TA9. Theory of Nuclear Spin Relaxation of Liquids for Large Surface-to-Volume Ratios. H. C. TORREY, *Rutgers University.**—Liquids have surface layers in which molecular motion is slower than in the bulk liquid and the local spin relaxation rate r_d correspondingly enhanced. If the diffusion time to the surface is shorter than the normal relaxation time, the extra relaxation rate of the entire liquid may be appreciable. The effect is described by a boundary value problem on the continuity equation (with dissipative term) for P (spin polarization). The solution gives $r_d = K(D_0 r_0)^{\frac{1}{2}}/b$; b is the volume-to-surface ratio; D_0, r_0 the self-diffusion coefficient and relaxation rate in bulk liquid, and K a dimensionless parameter. Let $D(x)$, $r(x)$ be the diffusion coefficient and relaxation rate in the surface layer (functions of position coordinate x). If Dr is constant (proportional model) out to position x_1 and $\partial P/\partial n = 0$ at $x = x_1$, than $K = \tanh \xi_1$ where $\xi_1 = (D_0 r_0)^{-\frac{1}{2}} \int_0^{x_1} r(x)dx$. Variation of r_d with temperature (T) and field (H) depends on the magnitude of ξ_1, and whether a stationary maximum in $r(x)$ exists inside the surface layer, as given in the table:

	r(max) inside layer	$r(x)$ monotonic
$\xi_1 \gg 1$	r_d indep. of T, H	r_d indep. of T, H
$\xi_1 \ll 1$	$r_d \propto H^{-1}$, dep. on T?	r_d indep. of H, not T

* Work supported by the California Research Corporation.

TA10. Measurements of Nuclear Spin Relaxation of Fluids in Bulk and for Large Surface-to-Volume Ratios. R. J. S. BROWN, *California Research Corporation.*—Nuclear spin relaxation curves have been obtained at various magnetic field strengths between one and 200 gauss by observing free precession in the earth's field for large samples. The surface contribution to the relaxation rate r_d for water in sands was found to be inversely proportional to mesh size. r_d for distilled or salt water in sand was found to be approximately independent of temperature. For a complex oil in bulk, nonexponential relaxation curves were obtained, which suggests a normal distribution of relaxation rates having a half-width of about one-quarter the average rate. Coefficients of diffusion and self-diffusion can be determined from the shapes of relaxation curves and also from the smallest relaxation rate for fluids in suitable porous media. Measurements are underway for systems involving emulsions, colloids, and other systems in which fluids have large surface areas, and the effects of surface active materials are being investigated. The measurements are also being extended to higher fields. An instrument is suggested wherein relaxation curves can be determined for relaxation at arbitrary (including low) field strengths, but where polarization is produced in strong fields and signals are observed in strong fields.

TA11. Interpretation of Data on Nuclear Spin Relaxation in Liquids for Large Surface-to-Volume Ratios.* J. KORRINGA, *The Ohio State University.*—A theoretical and quantitative evaluation of experiments gives the values of the extra relaxation rate r_d for water in fine water-wettable sands and/or small glass beads (which were found independent of T, proportional to $1/b$, and independent of H for $0 < H \leqslant 200$ g) and shows that $K = 1$. All this agrees with the proportional model, if in $K = \tanh \xi_1$, $\xi_1 \gg 1$ for $H \leqslant 200$ g, showing that the water layer is firmly bound to the sand, and at least 700 A thick. r_d for water in a treated (nonwater-wettable) sand gave $K = 0.2$ at $H = 5$ g and $K = 0.1$ at $H = 200$ g, which indicates a loosely bound layer with surface correlation time $\tau_0 \approx 4 \times 10^{-7}$ sec and thickness of about 50 A. Water in other treated sands gave similar, though not identical, results, as did a light hydrocarbon in untreated sand. The hydrocarbon in treated sands gave results complementary to those for water; in one sample r_d decreased by a factor 12 when H increased from 5 g to 200 g, indicating a firmly bound, thin layer. The untreated sand, saturated with water, then flushed with oil, yielded three distinct rates, interpretable as a coating of water on sand, oil drops in water, and oil drops partially contacting the sand.

* This work was done at the California Research Corporation, La Habra, California.

TA12. B^{11} Nuclear Magnetic Resonance in Crystalline Boron Carbide.* A. H. SILVER AND P. J. BRAY, *Brown University.*—The nmr of B^{11} has been observed at 7.18 Mcps in boron carbide using a Pound-Watkins-type spectrometer. Crystalline boron carbide powder from Bios Laboratories, Inc., showed broadening of the line toward low frequencies. Vacuum annealing for 15 hr at 750°C decreased the intensity while broadening the line. Cold-working of these powders increased the intensity and produced only slight changes in line shape. A polycrystalline sample of B_4C with excess B (from the Norton Company) showed a narrower line than any of the Bios samples. A B_4C single crystal showed an orientation dependent splitting of the observed resonance line. The asymmetry of the polycrystalline resonances and the splitting of the single-crystal line can be interpreted in terms of second-order quadrupole shifts of the central, $m = \frac{1}{2} \rightarrow -\frac{1}{2}$ resonance line of one-half the boron atoms. The changes in the powder resonances are attributed to the preferential displacement[1] of atoms from their proper sites to certain interstitial positions.[2]

* Research supported by the U. S. Atomic Energy Commission.
[1] Tucker and Senio, Acta Cryst. **8**, 371 (1955).
[2] Clark and Hoard, J. Am. Chem. Soc. **65**, 2115 (1943).

TA13. Magnetic Resonance in Spin Systems.* A. ZAHLAN AND E. P. GROSS, *Syracuse University.*—We consider two spins

coupled to external magnetic fields and to each other by exchange and dipolar energies. Starting from the Liouville equation obeyed by the density matrix, we multiply by the dipole moment operator and take the trace. This yields an equation for the rate of change of the magnetization which is the cross product of magnetization and field, plus traces containing two spin operators which arise from the dipolar energy. Equations for the change of the traces are obtained in like manner, and the process terminates because of the properties of the spin matrices. For spins of $\frac{1}{2}\hbar$ there are nine coupled linear equations. If the equations are completed by an instantaneous field relaxation term, a full discussion of line positions, widths, and of coherence, saturation, and thermodynamic aspects is possible. The introduction of spin lattice relaxation by the method of Bloembergen, Purcell, and Pound requires in the general case solution of equations with stochastically varying coefficients.

* Research supported by the Office of Scientific Research.

SATURDAY MORNING AT 9:30

NBS, East Building

(F. G. BRICKWEDDE presiding)

Cryogenics

U1. A Thermal Rectifier for Magnetic Cooling.* C. P. HWANG, C. D. FULTON, AND W. M. FAIRBANK, *Duke University.*—In magnetic cooling it would be desirable to use an automatic thermal valve, i.e., a connector having an inherently unidirectional heat conductivity. We are investigating the upward and downward heat conductivity of a liquid mixture of He^3 and He^4 confined in a vertical tube extending from the salt downward to the helium bath. When the salt is cold, heat flush concentrates the He^3 at the top of the tube and heat conduction is prevented. When the salt is warm, heat flush tends to concentrate the He^3 at the bottom, where in a small tube it may rest in a pocket outside the heat path or in a large tube it may undergo convection, in either case resulting in heat conduction. Preliminary experiments have been performed with a mixture containing 3% He^3 in a stainless steel capillary 4 in. long and 0.017 in. in inside diameter connecting 26 g of chrome alum with the helium bath. The heat of magnetization is conducted away in a few minutes while the warmup time after demagnetization is several hours. Experiments utilizing two such thermal rectifiers and two salt containers are being designed for cyclic magnetic cooling.

* This work is being supported in part by the National Science Foundation and the Office of Ordnance Research.

U2. Relation of the Superconductivity Criterion to the Electron Specific Heat. RICHARD A. FERRELL, *University of Maryland.*—A simplified derivation of the superconductivity criterion is given in which no attempt is made to describe the superconducting state. Superconductivity is instead identified by an instability in the Fermi distribution, which occurs when the product of the square of the electron-lattice interaction strength times the electron density of states is large enough to satisfy a certain inequality. The resulting criterion is equivalent to Frohlich's[1] when the latter is corrected by a factor of one-half. The dependence on the density of states agrees with the observed correlation between transition temperature and electron specific heat for the transition metals.[2] In cases where the superconductivity criterion is not satisfied the electron-lattice interaction still affects other metallic properties,[1] such as the Sommerfeld electron specific heat, which is increased by a factor always greater than unity. Although this factor can, in general, be large, an electron-gas calculation for sodium gives 1.25. A Wigner-Seitz treatment gives a value even closer to unity and disagrees with the observed value[2] of 1.6.

[1] H. Frohlich, Phys. Rev. **79**, 845 (1950); M. J. Buckingham, Nature **168**, 281 (1951).
[2] B. T. Matthias, Phys. Rev. **97**, 74 (1955); D. H. Parkinson and J. E. Quarrington, Proc. Phys. Soc. (London) **A68**, 762 (1955).

U3. Evaluation of Hyperfine Coupling in Transition Metals by Low-Temperature Specific Heats. C. V. HEER AND R. A. ERICKSON, *The Ohio State University.*—The recent work by Kurti[1] *et al.* on the orientation of the nuclei in a single crystal of metallic cobalt indicates that the hyperfine coupling in the metal is about 3 times smaller than in the Tutton salt. The contribution of the hyperfine coupling to the specific heat is estimated for a coupling constant of $A \simeq 0.01$ cm^{-1}. The relative contributions to the specific heat are as follows: hyperfine coupling specific heat $\simeq 2.7\times10^{-4}/T^2$ cal/mole; electronic specific heat $\cong 12\times10^{-4}T$ cal/mole; lattice specific heat $\cong 5.3\times10^{-6}T^3$ cal/mole. The importance of specific heat measurements in the temperature range 0.1 to 1°K are readily apparent and experiments on cobalt are currently in progress. The experimental apparatus, and the application of this technique to a number of ferromagnetic and antiferromagnetic elements, alloys, or compounds suitable for experimental investigation will be discussed.

[1] Grace, Johnson, Kurti, Scurlock, and Taylor, "Nuclear orientation in metallic cobalt," Conference on Low Temperature Physics, Paris, (1955).

U4. Coordination Quenching of the Saturation Magnetization of Potassium Ferricyanide. WARREN E. HENRY, *U. S. Naval Research Laboratory.*—The magnetization, at liquid helium temperatures and in magnetic fields up to 60 000 gauss, has been measured for polycrystalline potassium ferricyanide to check a prediction by Van Vleck[1] that the orbital degeneracy of Fe^{+++} with a ^6S ground state could be reduced by large interatomic forces and that through destruction of Russell-Saunders coupling, the higher levels could be well separated from the low-lying triplet (Kramer's degeneracy). We measure the moment directly as saturation is approached for 5 electrons occupying 3 levels at low temperatures. Whereas, the normal saturation moment[2] for Fe^{+++} is 5 Bohr magnetons per atom of iron, the approach to saturation for potassium ferricyanide indicates 1 Bohr magneton per atom of iron. The Pauli exclusion principle demands antiparallel orientations in the first two levels and a remaining one electron is in the third level. Although our experimental curve does not follow a Brillouin function for one free spin, H/T dependence is exhibited and the highest moment (0.97 Bohr magneton per atom) is approaching the average value, 1 Bohr magneton per atom as predicted by Van Vleck.

[1] J. H. Van Vleck, J. Chem. Phys. **3**, 807 (1935); J. B. Howard, J. Chem. Phys. **3**, 813 (1935).
[2] W. E. Henry, Phys. Rev. **88**, 559 (1952).

U5. High-Frequency Magnetoresistance of Metals at 4°K. E. FAWCETT, *National Research Council.*—Experiments are

in progress to measure the surface resistance at 24 kMcps of metals at helium temperatures in magnetic fields up to 16 kg. Each plane metal specimen is measured with the magnetic field in its surface both parallel and perpendicular to the linearly polarized high-frequency electric field. It is intended to present detailed experimental results for a number of metals and compare these with theory.

U6. Size Effects in the Superconductivity of Cadmium. R. A. HEIN AND M. C. STEELE,* *U. S. Naval Research Laboratory.*—The critical magnetic field curve of superconducting cadmium has been investigated as a function of particle size. Five size groups have been studied ranging from the bulk material down to spheres of 44 micron diameter. These spheres were prepared by whipping the molten metal in a bath of hot silicon oil.[1] While all the specimens yielded the same transition temperature, 0.555 ± 0.005°K, a systematic increase in the critical field curves was observed with decreasing particle size. These results substantiate the effect previously reported[2] and because of experimental refinements, are felt to be more acceptable. If this increase in the critical field curves is interpreted as being due to the particle size becoming comparable to the penetration depth (λ), then $\lambda_{T=0°K}$ is found to be 10×10^{-4} cm. This value is about 100 times the figure quoted for Hg, Pb, Sn, and Al. The temperature dependence of the penetration depth, so obtained, follows the empirical relationship of Daunt.[3]

* Now with the RCA Laboratory.
[1] M. C. Steele, Phys. Rev. **78**, 791 (1950).
[2] M. C. Steele and R. A. Hein, Phys. Rev. **87**, 908 (1952).
[3] Daunt, Miller, Pippard, and Shoenberg, Phys. Rev. **74**, 842 (1948).

U7. Compression of Solid Helium and Other Condensed Gases at Low Temperature.* JOHN W. STEWART, *University of Virginia.*—The previously reported[1] piston displacement technique for measuring compressibilities at low temperature has been carried up to pressures of 20 000 kg/cm². The earlier work on solid hydrogen, neon, and argon has been verified and extended, and a rough preliminary value obtained for the compression of solid helium at 4°K. In the case of helium, the compression at pressures below 2000 kg/cm² and the correlation with molar volumes had to be obtained from the indirect measurements of Dugdale and Simon with which our results seem to be consistent. The molar volumes of hydrogen are based upon the observations of Megaw. The results at 4°K follow:

	Helium		Hydrogen		Neon
Pressure kg/cm²	$\frac{V}{V_{2000}}$	Molar Volume cm³	$\frac{V}{V_0}$	Molar Volume cm³	$\frac{V}{V_0}$
0	—	—	1.000	22.65	1.000
143	—	17.1	0.945	21.4	—
2000	1.00	10.8	0.713	16.1	0.885
4000	0.87	9.4	0.632	14.3	0.832
10000	0.70	7.6	0.523	11.8	0.747
18000	0.60	6.5	0.455	10.3	0.682

* Supported by the Office of Ordnance Research, U. S. Army.
[1] J. W. Stewart, Phys. Rev. **97**, 578 (1955).

U8. Coefficient of Vaporization of Liquid Helium.* B. ROSENBAUM AND K. R. ATKINS, *University of Pennsylvania.*—Measurements have been made of the coefficient of vaporization α of liquid helium at $T = 1.1$°K. The method is a distillation process employing an inverted "U"-tube partly immersed in a helium bath. Constant power supplied to the liquid in the closed limb of the "U"-tube distills the liquid to the second limb, which is open to the bath. The rate of fall of the liquid level in the closed limb is observed, and the temperature difference ΔT between the limbs is measured with the aid of carbon resistance thermometers. Using simple kinetic theory and hydrodynamic considerations, the pressure discontinuity ΔP across the liquid level can be deduced and related to the rate of distillation via the coefficient of vaporization. A correction must be made for film flow. α is found to be unity within the limits of experimental error. The relevance of these results to certain film flow experiments will be discussed.

* Supported in part by a grant from the National Science Foundation.

U9. Flow of Liquid Helium through Porous Vycor Glass.* H. SEKI, K. R. ATKINS, AND E. U. CONDON, *University of Pennsylvania.*—It has already been observed[1,2] that superfluidity in thin helium films sets in at an "onset" temperature below the accepted lambda point of the bulk liquid. We have observed similar phenomena for flow through porous Vycor glass[3] with pore diameters of the order 50 A, which is less than the thickness of the saturated helium film. The onset temperature of the flow through these pores varies from 1.36°K to 1.77°K for different samples of glass. The rate of flow varied nonlinearly with the pressure head, but we are not yet certain to what extent this was due to thermal effects.

* Supported in part by a grant from the National Science Foundation.
[1] Bowers, Brewer, and Mendelssohn, Phil. Mag. **42**, 1445 (1951).
[2] E. A. Long and L. Meyer, Phys. Rev. **87**, 153 (1952).
[3] M. E. Nordberg, J. Am. Ceram. Soc. **27**, 299 (1944). We are very grateful to Dr. Nordberg for supplying us with samples of this glass.

U10. A Phase Separation in He^3–He^4 Solutions below 0.6°K.* G. K. WALTERS AND WILLIAM M. FAIRBANK, *Duke University.*—In investigating by use of magnetic resonance techniques the nuclear susceptibility below 1°K of a 40% solution of liquid He^3 in He^4, we have discovered a phase separation in which the enriched He^3 phase floats to the surface. A peculiar discontinuity in the nuclear susceptibility of a 38% solution of He^3 in He^4 had previously been reported by us. In order to demonstrate whether or not this was caused by a phase separation in the He^3–He^4 solution, the sample was moved to the edge of the magnet under which conditions the steady magnetic field decreased from the bottom to the top of the sample container. Thus the shape of the resonance signal as displayed on an oscilloscope could be used to determine roughly the distribution of He^3 in the container. As the temperature decreased below approximately 0.6°K, the portion of the signal corresponding to the top of the container became progressively larger with respect to that representing the bottom. This we interpret as a phase separation in which the He^3 rich portion floats to the top of the container. No such change of line shape was observed with pure He^3. A new container divided into three compartments is being constructed.

* This work was supported in part by the Office of Ordnance Research.

U11. Observations below the Lambda Point Using a Liquid Helium Bubble Chamber.* W. M. FAIRBANK, M. E. BLEVINS, M. M. BLOCK, M. J. BUCKINGHAM, E. M. HARTH, AND G. G. SLAUGHTER, *Duke University.*—The liquid helium bubble chamber described in another abstract of this meeting offers a method of studying the properties of helium below the lambda point under rapid decompression. Expansion of the liquid is achieved by moving a Teflon piston in contact with the liquid and photographing with a flash of about 0.3-millisecond duration, which is delayed relative to the time of expansion by a controllable amount. The time required to expand the volume of the liquid by ½% is about 3 milliseconds with shorter times for smaller expansions. For volume expansions as low as 0.05% bubbles have been photographed in the liquid at 2.1°K with flash delays of 3 milliseconds and longer. The presence or absence of a strong gamma-ray source does not apparently effect the number of these bubbles and no tracks of ionizing particles have been observed to date below the lambda point. Large bubbles up to 1 cm in diameter have been observed with volume expansions of 0.15% and larger, and flash delays of 10 to 15 milliseconds. These appear to be caused by spontaneous cavitation of the liquid.

* This work was supported in part by the Office of Ordnance Research, the Office of Naval Research, and the U. S. Atomic Energy Commission.

SATURDAY MORNING AT 9:30

Sheraton Park, Burgundy Room

(S. K. ALLISON presiding)

Nuclear Emulsions; General Nuclear Physics

UA1. Sensitivity Variation of Nuclear Emulsions with Temperature.* R. W. WANIEK, *Harvard University.*—An experiment aimed at detecting the temperature dependence of the sensitivity of nuclear emulsions was conducted in the external proton beam of the Harvard synchrocyclotron. Unsupported G5 pellicules, 200μ thick, were exposed in a cryostat at temperatures ranging from 4°K to 340°K. The 96-Mev proton beam traversed the plates at an angle of 14°, and the monitored irradiation intensities were kept the same for all plates exposed. Temperatures were recorded by a system of thermocouples and sensing elements embedded between emulsions. After exposure, all emulsions were maintained at the same temperature (18°C), and then developed together under carefully controlled conditions. Scanning was performed by grain and blob counting. Grain densities per 100μ are taken as an indication of the sensitivity. The results exhibit a fluctuating behavior at the high temperatures (10° to 65°C), a maximum near −40°C, a decreasing sensitivity from −40° to −180°C (the liquid-nitrogen point is about 75% of the 20°C sensitivity), and a liquid-helium point which is higher than the one at liquid-nitrogen temperature. The effect of retained sensitivity at low temperatures is used for exposures in connection with the high field nuclear track magnet.[1]

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] H. P. Furth and R. W. Waniek, Bull. Am. Phys. Soc., Series II, 1, No. 4, 226 (1956).

UA2. Controlled Development for Nuclear Emulsions.* JACQUES M. BLUM,† *University of Rochester.*—In order to obtain a desired and reproducible degree of development of nuclear emulsions, we have tried a new method of development. This one consists in separating the hot phase of the development (Brussel's method) in two or more times. The stack of plates is, first, just a little underdeveloped, then only one of the plates is fixed, washed, and dried. During a period which can be as long as two weeks, the other plates are put in a preservative bath after their development has been stopped and all the plates washed. A measurement on a track at minimum ionization on the fixed plate, can, with the aid of a chart, tell us the temperature and the time necessary for developing the stack of plates at the second time and so obtain the desired degree of development. Further measurements are now being made. Comparison of these results with the standard method will be made.

* This work is supported in part by the Office of Scientific Research.
† On leave of absence from the Laboratoire de Chimie Physique, Faculté des Sciences de Paris. Appointment supported by the OEEC.

UA3. A Photoelectric Densitometer.* E. P. NEY, JOHN NAUGLE, AND P. S. FREIER, *University of Minnesota.*—A rotating cube densitometer using the scanning mechanism of Monellet[1] has been developed to measure the ionization of charged particles in photographic emulsions. The instrument can be used over the entire range of ionization encountered, that is, from minimum ionization for charge one particles to the ionization of an iron nucleus at maximum. The result of the measurement for ionization greater than 50 times minimum can be expressed in terms of the equivalent wire diameter that the track represents and may be made independent of the dip angle and the depth in the emulsion. The result of the measurement in the range of ionization from 1 to 50 times minimum can be corrected for depth and dip of the track. Results of measurements in various ranges of ionization will be shown. These measurements give some information on the response of photographic emulsions to the ionization.

* This work was supported by a grant from the Graduate School of the University of Minnesota and assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] I. D. Monellet, *Proceedings of the Bagnere Conference*, p. 69.

UA4. Investigation of Nuclear Size by Precision Measurement of X-Ray Fine Structure.* ROBERT L. SHACKLETT,† AND JESSE W. M. DU MOND, *California Institute of Technology.*—Schawlow and Townes[1] have shown that the theoretical expression for $L_{II}-L_{III}$ x-ray level splitting for a point nucleus must be modified by the factor $\{1-D\exp[b(Z-60)]\}$ to correct for the effect of finite nuclear size. Their comparison of the theory to existing x-ray data by a least squares process[1] yielded a value of $D=1.42\times10^{-4}$ which, if interpreted in terms of a uniformly charged nucleus, indicated a nuclear radius $r=(2.1\pm0.2)\times10^{-13}A^{\frac{1}{3}}$ cm which is inconsistent with other determinations of this quantity. We have recently completed precision measurements on the $L_{II}-L_{III}$ level splitting in six of the heavy elements using two-crystal spectrometer techniques. A comparison of our results to the Schawlow-Townes theory gives a value of $D=0.54\times10^{-4}$ which corresponds roughly, to a nuclear radius of $r=1.2\times10^{-13}A^{\frac{1}{3}}$ cm. A brief description of the experiment, its precision, and the calculations will be given along with a discussion of the significance of the results.

* This work was supported by the U. S. Atomic Energy Commission.
† Now at the Department of Physics, Fresno State College.
[1] A. L. Schawlow and C. H. Townes, Phys. Rev. **100**, 1273 (1955).

UA5. An Attempt to Detect the Neutrinos from a Nuclear Reactor by the $Cl^{37}(\bar{\nu},\bar{e})A^{37}$ Reaction.* RAYMOND DAVIS, JR., *Brookhaven National Laboratory.*—An experiment has been performed in which 1000 gallons of carbon tetrachloride has been irradiated adjacent to a reactor at the Savannah River plant. At this location a high neutrino flux was anticipated along with good shielding from cosmic radiation. The procedures for removing and counting the A^{37} were the same as reported previously.[1] The preliminary result is that the cross section for the reaction is less than 0.9×10^{-45} cm²/atom. The theoretically expected cross section assuming neutrinos and antineutrinos are identical is 2.6×10^{-45} cm²/atom based upon measurements of the gross beta spectrum for U^{235} fission products.[2]

* Research performed under the auspices of the U. S. Atomic Energy Commission.
[1] R. Davis, Jr., Phys. Rev. **97**, 766 (1955).
[2] C. O. Muehlhause and S. Oleksa, Phys. Rev. **100**, 1266(A) (1955).

UA6. Effects of Valence States of Atoms on the Stopping of Swift-Charged Particles in Matter. WERNER BRANDT, *duPont Experimental Station.*—Bragg's rule for the stopping of swift-charged particles in matter states that the stopping power of compounds is given by the sum of the stopping powers of the component elements. Slight deviations from this rule can be expected for compounds of light elements. Here, the largest fraction of stopping electrons reside in valence shells, their stopping power hence being influenced by the valence states of the atoms. Three valence state effects on the stopping power are considered: the intramolecular interaction or chemical bond effect, the intermolecular interaction effect,

and the polarization effect. Available experimental stopping powers for 340 Mev protons were corrected for such effects to obtain the mean excitation potential, I_0, of atoms in reference states to which Bragg's rule should hold exactly. It was found that the uncertainties of the mean excitation potentials, I_{val}, of an atom in different states, when corrected for polarization effects, impede a clear confirmation of the proposed monotonic dependence of I_{val} on the atomic polarizability. It was found further, that the I_0 values of different elements depend, within the accuracy of their determination and correction, on their atomic number, Z, as $I_0=8.9Z(1+0.68Z^{-1})$ (ev). The functional form of this Z-dependence was predicted by Jensen from the dynamic Thomas-Fermi-Dirac model of the atom.

UA7. Nucleon Interaction Energies in Nuclei from Iron to Zinc.* KARL S. QUISENBERRY, T. T. SCOLMAN,† AND A. O. NIER, *University of Minnesota.*—The large double-focusing mass spectrometer developed at this laboratory has been used to determine, by the doublet method, the atomic mass of the stable isotopes of iron, cobalt, nickel, copper, and zinc. These masses are judged to be correct to about 1 part in 10 000 000. Mass values for the unstable isotopes of these elements have been calculated from the stable isotopic masses by using nuclear reaction and β-decay energy data. The resulting series of masses is sufficiently accurate to allow the calculation with useful precision of the binding energies of individual nucleons in these nuclei. The binding energy of the last proton and last neutron was found here and certain systematic variations are observed. Additionally, nucleon pairing energy was calculated for the last neutron and last proton pair wherever possible. An attempt to relate the relative magnitude of this pairing energy with the relative magnitude of the orbital angular momentum of the two nucleons was only partially successful. Pairing energy is apparently influenced by the presence of an unpaired nucleon of the other type.

* Research supported by the National Science Foundation.
† Now at Los Alamos Scientific Laboratory.

UA8. Magnetic Moment of the Proton.* KENNETH R. TRIGGER, *Los Alamos Scientific Laboratory.*—The method of Bloch and Jeffries was employed to obtain a measurement of the proton moment in units of the nuclear magneton. Experimental results agree with those of Jeffries.[1] However, theoretical calculations of the cyclotron orbits yield a set of three-coupled nonlinear equations which predict a frequency shift dependent upon the decelerating voltage. Evaluating the experimental data in view of this theory, one obtains the value $\mu_p/\mu_n=2.79275\pm0.00010$, including diamagnetic correction.

* Experimental work supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission at Stanford University.
[1] C. D. Jeffries, Phys. Rev. **80**, 305 (1950).

SATURDAY MORNING AT 9:30

Sheraton Park, Continental Room

(A. M. WEINBERG presiding)

Invited Papers in Nuclear Physics

V1. A Survey of the Angular Distribution of Scattered Neutrons. ALEXANDER LANGSDORF, JR., *Argonne National Laboratory.* (30 min.)

V2. A 7.7-Meter, Bent-Crystal Spectrometer for Capture Gamma Rays. B. HAMERMESH, *Argonne National Laboratory.* (30 min.)

V3. The 68-Mev Proton Linear Accelerator at the University of Minnesota. J. H. WILLIAMS, *University of Minnesota.* (30 min.)

V4. Shell-Model Theory of Collective Nuclear Oscillations. R. A. FERRELL, *University of Maryland.* (30 min.)

V5. Charge States in Rare Gases Following Internal Conversion and Beta Emission. A. H. SNELL, *Oak Ridge National Laboratory.* (30 min.)

SATURDAY MORNING AT 9:30

Sheraton Park, Caribar-Mural Room

(R. P. FEYNMAN presiding)

Theoretical Physics, V: Statistical Mechanics

VA1. Applicability of the Langevin Equation to Irreversible Processes.* ARMAND SIEGEL, *Boston University.*—Onsager and Machlup[1] have proposed the Langevin equation, $R\dot{\alpha}+s\alpha=\epsilon(t)$, as a general equation of motion for a fluctuating thermodynamic variable. In an idealized treatment, the fluctuating force $\epsilon(t)$ is considered uncorrelated with itself from one instant to another, and Gaussianly distributed. $\alpha(t)$ then has a determinate part $\alpha(0)\cdot\exp(-t\cdot s/R)$, and a stochastic part $\alpha_s(t)$. In reality, of course, $\epsilon(t)$ consists of discrete elementary processes. Under certain circumstances the main details of the idealized $\alpha_s(t)$ may show up only within intervals shorter than the time between elementary processes. The stochastic description is then largely fictitious. A limit to its applicability may be sought in the simple physical situation of the Brownian motion: α=velocity of the colloid particle. Using results of elementary kinetic theory, and assuming Stokes friction, the

Langevin description is found to be applicable if $mL/M\rho \ll (k/s)^{\frac{1}{2}}/\alpha$. m, M are masses of molecule of the medium and colloid particle; L, mean free path of a molecule in the medium; ρ, radius of the colloid particle; k is Boltzmann's constant.

* This work supported by U. S. Air Force through the Air Force Office of Scientific Research, Air Research and Development Command.
[1] L. Onsager and S. Machlup, Phys. Rev. **91**, 1505 (1953); see also A. Siegel, "The stochastic basis of Onsager's minimum principle" (to be published).

VA2. Brownian-Like Motion of a Heavy Particle Suspended on an Elastic String. ROBERT J. RUBIN, *University of Illinois.*—The solution of the equation of motion for the system consisting of a heavy mass M suspended on an elastic string is obtained for arbitrary initial displacements and velocities of the string. It is shown that the equation of motion of the mass M satisfies a Langevin equation[1] in which (1) the "friction constant" is $(a\rho/M)$ where a is the velocity of wave propagation and ρ is the mass per unit length of the string, and (2) the "fluctuating force" term is proportional to $u_0(at)+(1/a)v_0(at)$, where $u_0(\alpha)$ and $v_0(\alpha)$ represent the initial displacements and velocities in the string. The frictional force acting on M, which is proportional to the velocity of M, can be regarded as being due to the interaction between M and the infinite number of degrees of freedom of the string. The statistical nature of the fluctuating force acting on M is directly related to the statistical form which is assumed for the initial velocities and displacements in the string.

[1] S. Chandrasekhar, Revs. Modern Phys. **15**, 1 (1943).

VA3. An Extended Wiener-Khintchine Theorem for Spatial Correlations of Macroscopic Stochastic Functions. M. N. MOORE, *North American Aviation.*—By expanding a stochastic function of space and time into a Fourier integral of traveling waves one can show that a Wiener-Khintchine-like relationship between spatial correlations and time-independent spectral density functions exists. Upon comparison of this relationship for the spatial case with that for the temporal, it is possible to reduce the spatial problem to an equivalent temporal problem which may then be solved by usual methods. This theorem has been successfully applied to the problem of random fluctuations of stress and strain in elastic isotropic Voigt solids and the resulting spatio-temporal correlations are quoted.

VA4. Generalization of Our Micromodel of Irreversible Processes.* JOEL L. LEBOWITZ† AND PETER G. BERGMANN, *Syracuse University.*—We have extended our model of a system that exchanges energy with its surroundings stochastically (and thereby approaches canonical distribution if the surroundings are at a definite temperature)[1] to the exchange of other physical variables, including the number of (identical) particles. For suitably constructed reservoirs the system will then approach a generalized canonical[2] or grand canonical[3] distribution. If the system interacts with several reservoirs whose intensive parameters have different values, a stationary irreversible process will result. Among the possible applications of the extended model is the treatment of electric currents and other particle fluxes. We have verified the validity of Onsager's reciprocal relations for such situations.

* Supported in part by Office of Scientific Research.
† General Electric Gerard Swope Fellow.
[1] Bergmann and Lebowitz, Phys. Rev. **99**, 578 (1955).
[2] Bergmann, Phys. Rev. **84**, 1026 (1951).
[3] J. W. Gibbs, *Collected Works* (Yale University Press, New Haven, 1948), Vol. II, Chap. XV.

VA5. Stochastic Boundary Conditions in Irreversible Processes.* H. SALWEN, W. SADOWSKI, AND P. G. BERGMANN, *Syracuse University.*—Bergmann and Lebowitz described the time-dependent interaction of open systems with their surroundings by introducing stochastic terms on the right-hand side of the Liouville equation in Γ space. Realistically, such interaction ordinarily takes place only in certain regions of physical space and thence also in limited domains of the Γ space. Accordingly, we are investigating the extreme case in which the causal Liouville equation is satisfied everywhere except on certain hypersurfaces. The dynamics of the stochastic integral operator is then replaced by "stochastic boundary conditions," integral conditions on the density function on the hypersurfaces. The form of the boundary conditions may be ascertained either by a transition to the limit of the region in which the original integral operator is nonzero or by the formal requirement that the Helmholtz potential of the ensemble decrease monotonically with time.

* Supported by the Office of Scientific Research.

VA6. Generalized Collective Coordinates.* JEROME K. PERCUS AND GEORGE J. YEVICK, *Stevens Institute of Technology.*—One can exactly rewrite the dynamical equations for N interacting particles in terms of $3N$ collective coordinates $q_k=\Sigma \exp ik\cdot x_j$. This exact reformulation[1] of the many body problem can be systematized with the aid of simple formal mathematical identities. These formal identities comprise powerful tools for the extension to new types of collective coordinates which can be of special importance for the roton or high wave number region. Two distinct possible methods exist for approaching the problem: (a) given the form of the collective coordinates, to express the Lagrangian in terms of these coordinates in such a way that approximations yield obvious physical content; (b) from the exact equations of motion, to produce a method which will yield the desired collective coordinates, i.e., coordinates which represent the dominant physical process singled out. For example, one may choose collective coordinates to best represent the force terms and rely on free particle limiting behavior to ascertain the remaining kinetic terms. In all these methods, the lack of a sharp distinction between an external force field and nonuniform density may be prominently displayed. This is of importance for nuclear theory.

* Supported by the Office of Naval Research.
[1] J. K. Percus and G. J. Yevick, Phys. Rev. **99**, 661 (A) (1955).

VA7. Some Remarks on the Role of Supplementary Variables in the Collective Treatment of the Many Body Problem.* GEORGE J. YEVICK AND JEROME K. PERCUS, *Stevens Institute of Technology.*—In an interesting paper by Bogoliubov and Zubarev,[1] the theory of supplementary coordinates is carried to its logical extreme for the ground state of Einstein-Bose system. The simple basic idea is that the N-body Schrodinger equation can be transformed exactly using an arbitrarily large number of variables possessing a correspondingly large number of supplementary relations. (Bogoliubov and Zubarev employ an infinite number of Fourier coefficients of the density as collective coordinates.) This method differs from the usual practice of imposing the supplementary conditions on the wave functions in that any solution of Schrodinger's equation is legitimate when transformed back to the original variables. Serious problems arise in approximating because superfluous solutions of the excited states coalesce to the less numerous true solutions. In the perturbation calculation for the ground state this will introduce an error. Furthermore, the boundedness of collective coordinates[2] which is due to the supplementary interrelations is lost at any finite stage of a perturbational calculation. In a more correct treatment,[3] e.g., finite integration, one can extend the method to Fermi-Dirac systems by imposing suitable boundary conditions.

* Supported in part by the Office of Naval Research.
[1] Bogoliubov and Zubarev, Soviet Physics (JETP) **1**, 71, 1955.
[2] J. K. Percus and G. J. Yevick, Bull. Am. Phys. Soc. Series II, **1**, No. 1, 26 (1956).

VA8. The Unrestricted Hartree-Fock Method.* G. W. PRATT, JR., *Lincoln Laboratory*, AND J. H. WOOD, *MIT*.—The unrestricted Hartree-Fock method is based on the use of a single determinant for the total wave function in which orbitals of the same n, 1, and m_l values but different m_s values are regarded as being independent. The functional form of these orbitals is determined by solving the set of variational equations which makes the total energy a minimum. In an atom with a net spin the charge density associated with an orbital $u(nlm_l, +\frac{1}{2})$ will differ from that of $u(nlm_l, -\frac{1}{2})$ since these functions are solutions of variational equations which differ in their exchange terms. It is shown using the Li atom as an example that these differences are not merely the result of using a single determinant which has improper symmetry but arise when the full spin degeneracy problem is carried through for Li. The effect can be described as an exchange polarization of the inner orbitals by the outer unpaired orbitals. Such polarization effects may be expected to be of importance in calculating the magnetic form factors of paramagnetic atoms and in hyperfine splittings since the magnetic field at the nucleus due to closed shell s-electrons will now not be self-canceling. Results of a calculation will be reported.

* The research in this document was supported jointly by the Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology and was supported in part by the Office of Naval Research.

VA9. Quantum-Mechanical Many-Body Hard Core Interaction. KERSON HUANG AND C. N. YANG, *Institute for Advanced Study*.—The system under consideration is an N-particle quantum mechanical system enclosed in a volume V, in which the particles interact via the two-body hard core potential, with hard core radius a. The problem is formulated in terms of a wave equation in $3N$-dimensions with certain boundary conditions. A multipole approach to the problem leads to a power series expansion in a. It is shown that to order a^2, one may replace the hard core potential by the Fermi pseudo-potential $(4\pi a\hbar^2/m)\delta(\mathbf{r}_1-\mathbf{r}_2)(\partial/\partial r_{12})r_{12}$. The problem is then treated in perturbation theory, with free particle states as unperturbed states. The first-order energy correction for a Bose system is found to be $(4\pi a\hbar^2/mV)(N^2-\frac{1}{2}N-\frac{1}{2}\Sigma_\alpha n_\alpha^2)$, where n_α are occupation numbers in the unperturbed state. Physical meanings of this equation will be discussed. Second-order energy corrections to the ground states of Bose and Fermi systems have also been derived. The partition function and all the virial coefficients for the Bose case has also been calculated to order a^2.

VA10. Hopf's q-Function and the X- and Y-Functions of Chandrasekhar. JEAN I. F. KING, *Air Force Cambridge Research Center*.—In his treatise[1] Chandrasekhar has obtained exact solutions for the emergent radiation under a wide variety of conditions. These exact solutions are expressible in terms of X- and Y-functions, first introduced and tabulated by him. For the radiation field in the interior (source function), however, he obtained only solutions in finite approximations. The exact source function for an equilibrium gray atmosphere of optical thickness τ_1 has been found to be

$$B(\tau)=\frac{3F}{4}\{\tau+Q+L[q(\tau)-q(\tau_1-\tau)]\},$$

where Q is the ratio of the second and first moments of X and Y, and L is the reciprocal of the first X- and Y-functional moment. Quite unexpectedly, the Hopf q-function turns out to be simply the ratio of Q and L, thus proportional to the second X- and Y-functional moment.

[1] S. Chandrasekhar, *Radiative Transfer* (Oxford University Press, New York, 1950).

VA11. A Modified Variational Calculation. E. EISNER, *The Texas Company, Bellaire*.—The variational evaluation of $\bar{Q}_n\equiv\langle n/Q/n\rangle/\langle n/n\rangle$, where $H/n\rangle=E_n/n\rangle$, introduces a wave function $/\phi\rangle$ which minimizes $\bar{H}_\phi$ under variation of parameters in some class of admissible trial functions. This wave function is then used to calculate $\bar{Q}_\phi$, an estimate for $\bar{Q}_n$. $\bar{H}_n$ is a lower bound for $\bar{H}_\phi$, but this property does not carry over to general Q. Since short of $/n\rangle$ there is no universal best wave function, a proper method should yield an optimum estimate for $\bar{Q}_n$ itself. Since $\langle n/H^iQH^k/n\rangle=\langle n/H^{i+k}/n\rangle\bar{Q}_n=E_n{}^{i+k}\langle n/Q/n\rangle$, we can define $F(x)=\Sigma_{jk}A_{jk}(\langle\phi/H^iQH^k/\phi\rangle/\langle\phi/H^{i+k}/\phi\rangle-x)^2$. The parameters of $/\phi\rangle$ can be varied to minimize F, which is positive if A's are positive, but $F(\bar{Q}_n)=0$. When accurate experimental E_n's are known, we may minimize $G(x)=\Sigma_{jk}B_{jk}(E_n{}^{i+k}\langle\phi/Q/\phi\rangle/\langle\phi/H^{i+k}/\phi\rangle-x)^2$. It seems possible to select trial functions such that complete point-by-point evaluations of F or G can be done on a high-speed digital computer.

VA12. Electron Photodetachment from the Negative Hydrogen Ion.* SYDNEY GELTMAN, *The Johns Hopkins University*.—Previous calculations[1] of the continuous absorption coefficient or electron photodetachment cross section for H^- were based on the use of a ground state function obtained through the Ritz variational method. Such functions, although giving good values for the energy, are generally inadequate for the determination of the dipole matrix element needed for the absorption coefficient. We have constructed initial and final state functions for which the following necessary conditions on the true wave functions are satisfied: (1) equality of dipole length, velocity, and acceleration matrix elements and (2) the $\langle r^2\rangle$ and f sum rules. Our constructed ground state function is also shown to be very reasonable on the basis of energy minimization. Preliminary estimates of the resulting photodetachment cross section from 1000 to 17 000 A are close to the best previously calculated curve,[2] which was found to be consistent with experiment.[3]

* This work supported by the Bureau of Ordnance, Department of the Navy, under NOrd 7386.
[1] S. Chandrasekhar, Revs. Modern Phys. **16**, 301 (1944).
[2] S. Chandrasekhar, Astrophys. J. **102**, 223, 395 (1945).
[3] L. M. Branscomb and S. J. Smith, Phys. Rev. **98**, 1028 (1955).

VA13. Probability Distribution of Ion Pairs. E. MERZBACHER AND J. R. HERRING, *University of North Carolina*.—For various purposes it is useful to know the probability distribution, $P_n(E)$, for the production of n-ion pairs when an electron of initial energy E comes to rest in a gas. Using the somewhat academic model of atomic hydrogen, and the Born approximation for inelastic cross sections down to the lowest energies, we have computed this distribution from the integral equation

$$P_n(E)=q_e(E)P_n(E-E_1)+\int_0^{E-I}q_i(E,T)\sum_{k=0}^{n-1}P_k(T)P_{n-k-1}(E-I-T)dT,$$

for the first few values of n. Here, E_1 is a mean excitation energy, I the ionization potential, $q_e(E)$ the relative probability for excitation, and $q_i(E,T)$ the relative probability for ionization, T being the kinetic energy of the ejected electron. For large values of E a very simple asymptotic formula can be given for $P_n(E)$, and it is found that for our model this expression represents the distribution with fair accuracy even at very low energies. The behavior of the mean and the variance of the distribution emerges in detail. Probability distributions for several simplified models of the collision process will be displayed and compared.

VA14. Coulomb Hole: A Short-Range Correction for Correlation in Electronic Wave Functions. JOHN HAWGOOD.* *MIT*.—An approximate N-electron wave function is improved

by being multiplied by a function of any of the inter-electronic distances r_{ij} which are small at the point considered. The correction is not applied over all space, making more feasible the study of problems with $N>2$. The error in Φ, an approximate solution to $H\Psi=E\Psi$, may be represented by $p=(H\Phi-E\Phi)/\Phi$; in the usual orbital approximation, $p\to\infty$ when $r_{ij}\to 0$, for electrons i and j of opposite spins. To remove such infinities, Φ is multiplied near $r_{ij}=0$ by a function which behaves like $(1+r_{ij}/2)$, the coefficient of r_{ij} not being variable.[1] For a two electron singlet, using the coordinates $\mathbf{r}=(\mathbf{r}_1+\mathbf{r}_2)/2$ and $\boldsymbol{\rho}=(\mathbf{r}_1-\mathbf{r}_2)/2$, the approximation Φ is multiplied by $e^{\rho-S}(1-\rho^3/S^3)+\rho^3/S^3$, only within the sphere $\rho<S(\mathbf{r})$. Near nuclei, the hole radius $S(\mathbf{r})$ should vary inversely as the one-electron potential; elsewhere, $S=$constant is permissible. For an atom, the form $S=kr$ is used: for He, $k\doteq 0.3$.

* King George VI Memorial Fellow, sponsored by the English-Speaking Union.

[1] J. Hawgood, Quarterly Progress Reports, Solid-State and Molecular Theory Group, MIT (October 15, 1955, January 15, 1956).

Saturday Afternoon at 1:30

NBS, Materials Testing

(M. A. Tuve presiding)

Transmutation and Nuclear Energy Levels, IV

W1. Excited States of S^{32}, S^{34}, Cl^{35}, and Cl^{37}.† P. M. Endt and C. H. Paris, *University of Utrecht*, and A. Sperduto and W. W. Buechner, *MIT*.—Thin barium-chloride targets have been bombarded with 7.04-Mev protons from the ONR generator, and the emerging proton and alpha-particle groups have been analyzed at 90 and 130 degrees with the broad-range spectrograph. The ground-state Q-values for the $Cl^{35}(p,\alpha)S^{32}$ and the $Cl^{37}(p,\alpha)S^{34}$ reactions were measured as 1.863 ± 0.008 and 3.026 ± 0.008 Mev, respectively. From the former reaction, levels in S^{32} were found at 2.237, 3.780, 4.287, 4.465, and 4.698 Mev. From the latter reaction, levels in S^{34} were found at 2.127, 3.302, 3.915, 4.073, 4.114, 4.621, 4.685, and 4.876 Mev. From the inelastically scattered proton groups, levels in Cl^{35} were observed at 1.221, 1.763, 2.645, 2.695, 3.006, 3.165, 4.058, 4.113, and 4.174 Mev, and in Cl^{37} at 0.838 and 1.728.

† This work has been supported in part by the joint program of the U. S. Atomic Energy Commission and the Office of Naval Research.

W2. Analysis of (dp) Reactions in Calcium Isotopes.* B. J. Raz† and J. B. French, *University of Rochester*.—An analysis has been made of the results of the MIT Van der Graaf group[1] on (dp) reactions leading to odd parity levels of Ca^{41}, Ca^{43}, and Ca^{45}. The results demonstrate that the coupling scheme is quite close to the jj-limit; more precisely they give a small value for the amplitudes of certain minor components of the wave functions (e.g., the $(f\,7/2)_0^2\,p\,\frac{3}{2}$ component of the lowest $J=\frac{3}{2}$ levels). These amplitudes are then used to determine certain features of the spin-independent part of the effective nuclear-nucleon interaction (assumed, as is customary, to be mainly central). The spin-dependent part is then approximately determined by considering the level spectrum. The final conclusions are that the interaction has quite a long-range and a large spin-independent part; quantitative estimates will be given. The conclusions are similar in general but not in detail to those of Levinson and Ford.[2]

*Work supported by the U. S. Atomic Energy Commission.
† Now at Argonne National Laboratory.
[1] Braams, Bockelman, Browne, Buechner, Cobb, and Guthe (unpublished).
[2] C. Levinson and K. W. Ford, Phys. Rev. **100**, 13 (1955).

W3. The $Ca^{40}(d,p)$ Reaction: Angular Distributions.* C. K. Bockelman,† *MIT*.—The angular distributions from 0°–60° of the protons emitted from a CaO target bombarded by 7.0-Mev deuterons from the MIT-ONR electrostatic generator have been obtained. The proton groups were analyzed in momentum by the MIT broad-range magnetic spectrograph. While a strong proton group from the $C^{12}(d,p)$ reaction obscures some Ca groups at certain angles, angular distributions were obtained for most of the 25 levels seen by Braams[1] below 4-Mev excitation in Ca^{41}. Where a comparison can be obtained, the agreement with the earlier measurements of Holt and Marsham[2] is good. Butler stripping curves appear to fit ten of the states measured; in other cases the characteristic forward maximum is not evident. Most of the γ rays emitted after neutron capture in Ca^{40} seen by Demidov[3] can be fitted in a scheme employing only those levels which show a stripping-type angular distribution.

* Supported in part by the Office of Naval Research.
† Now at Yale University, New Haven, Connecticut.
[1] C. M. Braams, Phys. Rev. (to be published).
[2] J. R. Holt and T. N. Marsham, Proc. Phys. Soc. (London) **A66**, 565 (1953).
[3] C. M. Braams (private communication).

W4. (d,p) Reactions of the Iron Isotopes.* A. Sperduto and W. W. Buechner, *MIT*.—Thin targets of natural iron and of iron enriched in Fe^{54}, Fe^{57}, and Fe^{58} have been bombarded with deuterons from the ONR generator, and the resulting proton groups have been studied with the broad-range magnetic spectrograph at angles of 10, 30, and 45 degrees. Incident deuteron energies of 6.54 and 7.01 Mev were used. The Q-values of the (d,p) reactions leading to the ground states of Fe^{55}, Fe^{57}, Fe^{58}, and Fe^{59} were found to be 7.073, 5.418, 7.808, and 4.350 Mev, respectively. In Fe^{55}, the first three levels found are at 0.413, 0.932, and 1.302; in Fe^{57}, at 0.015, 0.135, and 0.365; in Fe^{58}, at 0.799, 1.644, and 2.041; in Fe^{59}, at 0.286, 0.473, and 0.728 Mev. For each of these nuclei, a large number of higher lying excited states have been measured, the regions of excitation studied being from the ground states to 7.6 Mev in Fe^{55}; 6.5 Mev in Fe^{57}; 8.3 Mev in Fe^{58}; and 6.2 Mev in Fe^{59}.

* This work has been supported in part by the joint program of the U. S. Atomic Energy Commission and the Office of Naval Research.

W5. Proton Capture Resonances in Co^{59}. C. R. Gossett, J. W. Butler, and H. D. Holmgren, *Naval Research Laboratory*.—As a continuation of our previous proton capture work,[1] we have utilized the same techniques to study the

$Co^{59}(p,\gamma)Ni^{60}$ reaction. Our preliminary excitation curves indicate an observed average level spacing of about 10 kev in the vicinity of 1.0 to 1.3 Mev. In our gamma-ray energy measurements we observe no ground-state transitions. The expected energy for such a gamma ray may be calculated from the Q-values of the $Co^{59}(d,p)Co^{60}$ [2] and $Co^{60}(\beta^-)Ni^{60}$ [3] reactions. From known spins and parities, the absence of ground state transitions is expected if only s-wave capture occurs. Excitation curves, cross sections, and gamma-ray energy measurements will be presented.

[1] Gossett, Butler, and Holmgren, Bull. Am. Phys. Soc. Series II, 1, No. 1, 40 (1956).
[2] Foglesong and Foxwell, Phys. Rev. 96, 1001 (1954).
[3] R. W. King, Revs. Modern Phys. 26, 327 (1954).

W6. (n,α) Cross-Section Measurements at 14 Mev. H. G. Blosser, T. H. Handley, and C. D. Goodman, *Oak Ridge National Laboratory.*—The 14-Mev (n,α) cross-section measurements reported previously[1] have been extended to the isotopes Co^{59}, Br^{79}, Nb^{93}, Pd^{105}, and Cs^{133}. Cross sections have been measured by standard activation techniques utilizing radiochemical separations and relative beta counting under end-window G.M. tubes. In addition, the measurements have been checked by calibrated gamma counting for those isotopes for which standardized sources could be obtained. Preliminary results indicate these measurements to be in agreement with the trend indicated by the earlier work.[1] This trend is an order of magnitude lower than that reported by Paul and Clarke[2] for this mass region and is in qualitative agreement with the prediction of statistical theory. Final results of the measurements will be presented and their implication with respect to statistical theory *vs.* direct interaction will be discussed.

[1] Blosser, Goodman, Handley, and Randolph, Phys. Rev. 100, 429 (1955).
[2] E. B. Paul and R. L. Clarke, Can. J. Phys. 31, 267 (1953).

W7. Protons from the Interaction of 14-Mev Neutrons with Zn^{64}.† L. Rosen and A. H. Armstrong, *Los Alamos Scientific Laboratory.*—In an attempt to determine the extent to which the large (n, charged particle) cross sections observed at 14 Mev are incompatible with the statistical model, a program has been initiated to measure the spectral and spatial distributions of the emitted particles. The experimental method involves the irradiation of a thin target of the element under study by a collimated beam of monoenergetic neutrons. The charged reaction products are detected by nuclear emulsions which surround the target in "good geometry." Of three isotopes thus far studied, only one, Zn^{64}, yields results which are not at variance with published data based upon activation measurements. The cross section for 14-Mev neutron-induced proton emission from Zn^{64} is 590 ± 75 mb, approximately half of which can be shown to be associated with (n,np) reactions. The shapes of the energy distributions of the protons from (n,np) and from (n,p) processes (but not the cross section corresponding to the latter reaction) are consistent with the predictions of the statistical model. The angular distribution is essentially symmetrical about 90° except for those protons (comprising less than 5% of the total) whose energy is greater than 8 Mev. These latter appear to be forward peaked, although not so strongly as the high-energy neutrons from 14-Mev neutron-induced reactions in Bi.

† Work performed under the auspices of the U. S. Atomic Energy Commission.

W8. Measurement of (p,xn) Cross Sections in Lead and Bismuth. R. E. Bell* and H. M. Skarsgard, *McGill University.*—The (p,xn) cross-section measurements reported previously[1] have been extended to cover $x=2$ to 7 in Bi^{209}, 2 to 6 in Pb^{206}, 2 to 4 in Pb^{207}, and 3 and 4 in Pb^{208}, using protons from the McGill synchrocyclotron over the energy range 10 to 85 Mev. The absolute accuracy is about 15%. The results from $x=3$ to 7 can be fitted with a compound nucleus plus prompt cascade model using reasonable nuclear parameters,[2] but the $(p,2n)$ cross section is experimentally nearly double the value predicted with the same parameters. Since (p,xn) reactions are dominant in the range 10 to 40 Mev, their sum approximates the total reaction cross section; this sum fluctuates around the smooth curve computed for the compound nucleus model with $r_0=1.3\times10^{-13}$ cm. The fluctuations are similar to, but more marked than, those in the total neutron cross sections of heavy elements in the same energy range.

* Staff member, Chalk River Laboratories.
[1] R. E. Bell, Phys. Rev. 95, 651 (A) (1954).
[2] J. D. Jackson, Phys. Rev. 95, 651 (A) (1954).

W9. (p,pn) Excitation Functions from 0.4 to 3.0 Bev.* Samuel S. Markowitz,† F. S. Rowland, and G. Friedlander, *Princeton University and Brookhaven National Laboratory.*—Excitation functions for (p,pn) reactions on F^{19}, Cu^{65}, Mo^{100}, and Ta^{181} have been measured by radiochemical methods over the energy range 0.4 to 3.0 Bev. Cross sections (in mb) for F^{19}, Cu^{65}, and Mo^{100} are presented in Table I. All the cross sections decrease from 0.4 to 1 Bev and then remain fairly constant. Similar results have been reported[1] for $C^{12}(p,pn)C^{11}$. The connection between the shapes of excitation functions for (p,pn) reactions and those for inelastic nucleon-nucleon collisions will be discussed. To check whether (p,pn) cross sections vary smoothly with mass number, (p,pn) reactions on the separated isotopes Fe^{54}, Ni^{58}, Cu^{63}, and Zn^{64} are being studied.

TABLE I.

Target	0.4	0.6	0.8	1.0	1.3	1.6	2.2	2.6	3.0 Bev
F^{19}	18	19	16	15	—	15	16	—	15
Cu^{65}	37	27	30	28	29	29	27	23	24
Mo^{100a}	75	69	59	56	58	—	52	59	52

[a] Includes growth of Mo^{99} from 2 m Nb^{99}, the $(p,2p)$ product.

* Work supported in part by the U. S. Atomic Energy Commission.
† Charlotte Elizabeth Procter Fellow, Princeton University.
[1] R. L. Wolfgang and G. Friedlander, Phys. Rev. 96, 190 (1954).

W10. Production of F^{18} and Na^{24} in Bev Proton Bombardments.* J. Hudis and A. A. Caretto, *Brookhaven National Laboratory.*—Excitation functions for the production of F^{18} and Na^{24} from Cu, Ag, Ta, Au, Pb, and U have been determined in the proton energy region between 1 and 3 Bev. The cross sections in mb for F^{18} production are tabulated in Table I. The Na^{24} cross sections are higher, but show the same variation with A and E. The data will be interpreted in terms of two different mechanisms for the production of F^{18} and Na^{24}. With targets of low and medium A (up to Ag) these products are thought to be predominantly spallation residues. Their formation from the remaining targets (Ta to U) may be

TABLE I.

E(Bev)	Al[a]	Cu	Ag	Au	Pb	U
1	7.1	0.45	0.18	0.075	0.047	0.34
2	6.0	0.92	0.44	0.20	0.40	1.49
3	5.3	1.18	1.11	0.51	0.59	1.72

[a] Friedlander, Hudis, and Wolfgang, Phys. Rev. 99, 263 (1955).

ascribed to fission which, with increasing energy in this region, appears to become more asymmetric.

* Research performed under the auspices of the U. S. Atomic Energy Commission.

W11. The $C^{12}(p,pn)C^{11}$ Cross Section from 2.0 to 3.0 Bev.* J. B. CUMMING, C. A. SWARTZ, AND G. FRIEDLANDER, *Brookhaven National Laboratory.*—The cross section for the production of C^{11} by high-energy protons incident on carbon has been measured in the external beam of the Brookhaven Cosmotron. A collimated, focused, and magnetically analyzed beam was brought out through a hole in the main shielding wall. The beam, less than ½ in. in diameter, was passed through a 1-in. diameter 1-in. thick plastic scintillator. The flux of protons in the beam was determined by a counter telescope immediately behind the scintillator. The C^{11} activity induced in the target was measured by internal scintillation counting with anticoincidence circuits to reduce the background. In an auxiliary experiment the contribution of secondary particles to the production of C^{11} in the thick target was determined and an appropriate correction applied. The results at 2.0, 2.6, and 3.0 Bev are 28.8, 26.7, and 27.9 mb, respectively, with an error of 7% in each case. These results are about 20% higher than those previously determined by an indirect method.[1]

* Research performed under the auspices of the U. S. Atomic Energy Commission.

[1] R. Wolfgang and G. Friedlander, Phys. Rev. **96**, 190 (1954); **98**, 1871 (1955).

W12. $C^{12}(p,pn)C^{11}$ Cross Section at 4.1 Bev.* N. HORWITZ, J. J. MURRAY, AND W. E. CRANDALL, *University of California, Berkeley.*—Work has been started at the Bevatron to measure the absolute cross section for the $C^{12}(p,pn)C^{11}$ reaction for bombarding proton energies of 360 Mev to 6 Bev. A report will be made of a preliminary measurement at 4.1 Bev. In this measurement a plastic scintillator was sandwiched between two photographic emulsions and exposed to the internal proton beam. The number of C^{11} nuclei was measured by counting the induced β activity in the scintillator, and the number of incident protons was determined by counting tracks in the emulsion. A cross section of 30.5 ± 1 mb was obtained. The ±1-mb error is due to statistical uncertainties only. It is felt that systematic errors are probably less than ±4 mb.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

SATURDAY AFTERNOON AT 1:30

Sheraton Park, Grand Ballroom

(J. A. BURTON presiding)

Solid-State Physics, III: Semiconductors

WA1. Diffusion Effects in Drift Mobility Measurements in Semiconductors. J. P. MCKELVEY, *Westinghouse Research Laboratories.*—Drift mobility measurements in semiconductors using small dc sweep fields rather than the usual large pulsed fields are described. It is necessary in such cases to take diffusion as well as drift into account in calculating the mobility from the transit time, and a calculation is made which considers both effects, resulting in a generalized transit time—drift mobility relation. Measurements of transit time *vs* sweep field show that the diffusion corrections are in good agreement with experiment, and that in cases of experimental interest the diffusion correction may be as large as 10%.

WA2. Injection Ratios, Lifetimes, and Trapping in Silicon.* J. MACZUK, R. M. SHOWERS, AND B. P. FABRICAND, *University of Pennsylvania.*—The method of Many[1] has been applied to the measurement of injection ratios and lifetimes in *n*- and *p*-type silicon samples. Injection was obtained from electroplated zinc and nickel on *p*-type samples, gold on *n*-type samples, and point contacts. Some injection ratios are 20% from electroplated contacts and 3% for point contacts for currents of 20 ma through the sample. The variation with sample current has been measured for one *p*-type sample, which yielded an injection ratio of 65% at 3 ma. Consistent measurements of lifetimes of minority carriers have been obtained in uniform samples without traps using these techniques. Lifetimes in the presence of traps have been measured by illuminating the sample with dc light. Certain samples show no change of resistance during the constant current pulse for some time interval, after which the expected resistance decay occurs. The time interval is eliminated by illumination, and lifetime measurements from both decay curves are equal. These observations furnish evidence for a trap in which both majority and minority carriers are held in an unrecombined state.

* This work was done under contract with the U. S. Signal Corps Engineering Laboratories, Fort Monmouth, New Jersey.

[1] A. Many, Proc. Phys. Soc. (London) **B67**, 9 (1954).

WA3. Absorption Spectrum of Germanium in the Vicinity of the $M_{2,3}$-Edge.* D. E. BEDO AND D. H. TOMBOULIAN, *Cornell University.*—The absorption spectrum of thin evaporated germanium foils was investigated in the spectral region extending from 60 A to 200 A. The vaporized semiconductor was condensed on a heated (400°C) substrate consisting of a Pyrex slide coated with Victawet and zapon layers. Following deposition, the foil was strengthened by a second layer of zapon and then was floated off of the glass by dissolving the wetting agent. The estimated thicknesses of the various absorbers ranged from 100 A to 2000 A. A dip in the absorption curve occurring at about 101 A is identified as the $M_{2,3}$ edge, corresponding to the onset of $3p\rightarrow$conduction band absorption. The wavelength position of the discontinuity is in accord with the previously[1] observed edge in the $M_{2,3}$ emission spectrum. The absorption coefficient, μ, on the low-energy side of the edge is approximately 1.8×10^5 cm^{-1}, while the change in μ at the edge is 0.3×10^5 cm^{-1}. This indicates considerable background absorption resulting from $3d$ and valence band electrons.

* Supported by the Office of Ordnance Research, U. S. Army.

[1] D. E. Bedo and D. H. Tomboulian, Phys. Rev. **100**, 1257 (1955).

WA4. Magnetic Field Dependence of the Thermoelectric Power of Germanium. M. C. STEELE, *RCA Laboratories.*—The thermoelectric power of an *n*-type Ge single crystal (10 ohm cm resistivity at room temperature) has been measured at several fixed temperatures as a function of magnetic field strengths up to 11 500 oersteds. The heat current was

parallel to a 111 axis, while H, the applied magnetic field, was perpendicular to the heat current. At 78°K, Q, the thermoelectric power, increased in magnitude (became more negative for the n-type crystal used) from -1990 to -2970 μv/°K, as H went from 0 to 11 500 oersteds. At low fields (up to about 2500 oersteds), Q increased as H^2, but at higher fields saturation effects became evident. Measurements at 236°K revealed an increase of only 2% in Q for a field of 11 500 oersteds. These results are in keeping with a phenomenological low field treatment of the effect which predicts that $\Delta Q/Q_0$, the relative change in Q, should be proportional to $(\mu H)^2$, where μ is the mobility.

WA5. On the Use of High Transient Magnetic Fields in Solid State Experimentation and Nuclear Track Plate Work.* H. P. FURTH AND R. W. WANIEK, *Harvard University.*—Experimental work with pulsed magnetic fields of a half-megagauss and more has been found practical.[1] Some results of magneto-resistance measurements in germanium are given, and the construction of magnets for cyclotron resonance experiments is discussed. The technique of nuclear track plate exposure in a magnetic field pulsed synchronously with a high-energy accelerator[2] is shown to be useful in hyperon studies.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] H. P. Furth and R. W. Waniek, Rev. Sci. Instr. (to be published).
[2] H. P. Furth and R. W. Waniek, Nuovo cimento **6**, 1350 (1955).

WA6. Optical Spectra of Ge-Si Alloys under Pressure.* WILLIAM PAUL, *Harvard University,* AND D. M. WARSCHAUER, *MIT.*—The absorption spectra of a number of Ge–Si alloys has been measured at hydrostatic pressures up to 8000 kg/cm². Germanium-rich alloys show a change of the energy gap with pressure quite similar to that of pure germanium, while the silicon-rich alloys exhibit behavior more like that of pure silicon than that of germanium. The change-over in the types of behavior, which are quite different,[1] gives indirect confirmation of the picture of the energy band structure of Ge–Si alloys suggested by Herman,[2] and of the pressure behavior of the conduction band minima involved as suggested by Paul and Brooks[3] and by Herman.

* The research in this document was supported jointly by Harvard University and by the Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.
[1] Warschauer, Paul, and Brooks, Phys. Rev. **98**, 1193 (A) (1955).
[2] F. Herman, Phys. Rev. **95**, 847–848 (1954).
[3] W. Paul and H. Brooks, Phys. Rev. **94**, 1128 (1954).

WA7. Thermoelectric Power in Gray Tin Filaments.* A. N. GOLAND AND A. W. EWALD, *Northwestern University.*—Thermoelectric power measurements have been carried out on gray tin filaments in the temperature range from 77 to 270°K. Data have been taken for pure samples, and for n-type and p-type samples with varying impurity concentrations. The electrical conductivity was simultaneously measured, and compared with that of similarly doped samples previously employed for Hall measurements.[1] Excellent agreement gave further evidence of the reproducibility of the properties of these samples. Pure samples are always n-type, and exhibit a maximum of approximately -100 μv/°K in the neighborhood of 100°K. Other n-type samples have a maximum of about -160 μv/°K at somewhat higher temperature, and this maximum shifts to higher temperature as the impurity concentration is increased. The p-type samples also exhibit a maximum of the order of 140–160 μv/°K which occurs in the range 90–100°K. All p-type samples become n-type as the temperature rises, and the crossover point shifts to higher temperature as impurity concentration increases. Preliminary analysis indicates that the phonon effect may be much more important in p-type than in n-type material.

* Work supported by the Office of Naval Research.
[1] E. E. Kohnke and A. W. Ewald, Phys. Rev. **100**, 1251 (A) (1955).

WA8. Tempersture Dependence of Resistivity of Lead-Excess PbTe. R. W. FRITTS AND S. KARRER, *Milwaukee Gas Specialty Company.*—Polycrystalline ingots of lead telluride containing stoichiometric excesses of 0.15 to 3.0% lead exhibit N-type electrical properties that are reproducible over a wide range of temperature. Such reproducibility is attained by hydrogen annealing the ingots after solidification to establish equilibrium between the primary PbTe phase and the minor lead-rich phase which suffers some segregation during freezing from the melt. The temperature dependence of lead solubility in the primary phase has been investigated by measuring resistivity and Hall effect at 25°C of ingots which were hydrogen annealed and quenched from various elevated temperatures. This data shows that there exists a concentration of lattice defects of the donor type arising from the equilibrium between the PbTe grains and the intergranular lead phase which exhibits a high positive temperature coefficient. The slope of the log resistivity *versus* reciprocal temperature curve gives 0.51 electron volt as the activation energy relating room temperature resistivity to quenching temperature. This temperature dependence of lead solubility must be considered in developing the equations relating carrier concentration for conductivity to ingot temperature.

WA9. On the Resistivity Discontinuity in Almost-Stoichiometric Sb_2Se_3. DONALD F. CLIFTON AND LEE GILDART, *University of Kentucky.*—A plot of the electrical resistivity of the semimetal compound Sb_2Se_3 (antimony triselenide) against weight percent of selenium shows a discontinuity (an increase) of four orders of magnitude as the proportion changes from stoichiometric through about 0.3% excess selenium.[1] Evidence will be presented to show that the effect can be accounted for by a model in which Sb_2Se_3 crystals are embedded in a matrix of glassy selenium.

[1] Cullity, Telkes, and Norton, J. Metals **2**, 47–53 (1950).

WA10. Electrical and Optical Properties of SnSe.* D. MITCHELL AND H. LEVINSTEIN, *Syracuse University.*—Several single crystals of SnSe have been grown by both zone leveling and the Stockbarger technique. The material has a sheet-like structure which may be cleaved as thin as 10 microns. This has made it possible to measure, by transmission, the optical absorption within the intrinsic region. The optical absorption edge from these measurements occurs at about 0.95 ev and shifts to higher energy with decreasing temperature. These results agree with earlier results for the photoconductive response of evaporated, polycrystalline films of the same material. The electrical properties have also been studied, yielding a "p" type mobility of 180 cm²/volt-sec, parallel to the cleavage planes, and having a $T^{-\frac{1}{2}}$ temperature dependence.

* Supported by the Office of Ordnance Research.

WA11. Self-Diffusion in InSb and GaSb. F. H. EISEN* AND C. E. BIRCHENALL, *Princeton University.*—Self-diffusion measurements have been made in the intermetallic compounds InSb and GaSb. The material used was single crystal or slightly polycrystalline. A tracer technique was used, in which layers were removed from the crystal progressively and the residual activity in the crystal was counted after each section was taken. A hold up on the surface of most of the radioactive tracer and the small magnitude of the diffusion coefficients limits the precision of the measurements and the temperature range over which they can be made with reasonable annealing times. The following values of D_0 and Q are obtained:

InSb	D_0(cm²/sec)	Q(kcal/mole)
In	0.05	41.8
Sb	0.05	44.6
GaSb		
Ga	3.2×10^2	72.6
Sb	3.4×10^4	79.4

The product of grain boundary diffusion coefficient and grain boundary width was found to be 3.8×10^{-16} cm³/sec at 502°C.

* Now at Atomics International, a division of North American Aviation, Inc.

WA12. Corbino Disk Magnetoresistivity Measurements on InSb. MILTON GREEN, *Signal Corps Engineering Laboratories.*—Magnetoresistivity measurements employing "Corbino disk" geometry have been made at temperatures of 77°K, 203°K, and 290°K on a slice of high-purity single-crystal InSb, which was obtained through the courtesy of Dr. Hans Fredrikse, of the National Bureau of Standards. Estimated donor concentration of the crystal is 10^{15} per cm³. Hall measurements for precise determination of carrier concentration is now in progress. In a field varying in strength from 0 to 20 kilogauss, the resistance of the Corbino disk at 77°K, 203°K, and 290°K, changed by factors of approximately 25, 22, and 35, respectively. The maximum magnetic coefficients of resistance of the sample, at the same temperatures are 0.5, 0.95, and 0.95 per kilogauss, respectively. There is very little separation between the characteristic curves, log R vs H, for 77°K and 203°K. In fact, they cross at $H=8$ kilogauss. The characteristic curve for 290° is considerably lower along the resistance axis. A possible explanation of the closeness of the low temperature curves is that the sample may contain considerable p type carrier concentration. Hall measurements will help to clarify this point.

SATURDAY AFTERNOON AT 1:30

Sheraton Park, Burgundy Room

(F. N. FRENKIEL presiding)

Fluid Dynamics; Atmospheric Physics

X1. Kinetic Theory of Couette Flow.* E. P. GROSS, E. A. JACKSON, AND S. ZIERING, *Syracuse University.*—We investigate the kinetic theory of plane shear flow, i.e., two infinite flat plates at a distance d, moving with a relative velocity U. For this simplest flow problem, exact solutions of the Navier-Stokes equations yielding flow pattern, temperature distribution, drag for arbitrary U are known. The theory of the infinite mean free path limit is also known. Interest therefore centers on the regions of mean free path comparable to d and high speeds. We develop an intuitive two stream constant free path model which links properly the known limits and which yields explicit and reasonable results in general. The model is related to a discrete ordinate method of solving the Boltzmann equation. We study the features of several iteration methods which give solutions satisfying the microscopic boundary conditions and which start from either Knudsen or Navier-Stokes limits. An analysis is made of the linearized (low-speed) solutions of Chang and Uhlenbeck and Mott-Smith.

* Research supported by the Office of Scientific Research.

X2. Measurements of Heat Transfer from Wires in Supersonic Flows.* JOHN LAUFER AND ROBERT MCCLELLAN, *California Institute of Technology.*—Results of an experimental investigation of the heat loss of fine heated wires immersed in a supersonic stream at right angles to the flow direction are presented. The Mach number range of the experiments was 1.3 to 4.5. It was found that the principal independent parameter of the problem is the Reynolds number, Re_2, based on conditions behind the detached normal shock wave, and the heat loss is independent of the free stream Mach number. The experiments covering a Reynolds number range of 3 to 220 show the existence of two flow regimes: (1) for $Re_2>20$, the cylinder equilibrium or unheated temperature is a constant, independent of the Reynolds number and has a value $T_e/T_t=0.95\pm0.01$; the Nusselt number varies with the square root of the Reynolds number for a given temperature loading; (2) for $Re_2<20$, the equilibrium temperature rises sharply with decreasing Reynolds number, in fact, it exceeds the stagnation temperature at about $Re_2<4$. The square root relationship between Nusselt and Reynolds numbers does not hold.

* Research done under the joint sponsorship of the Department of the Army, Ordnance Corps, and the Department of the Air Force.

X3. Interferometric Analysis of the *N*-Wave of a Slender, Supersonic Projectile. D. H. STEININGER AND F. D. BENNETT, *Ballistic Research Laboratories.*—Previous interferometric studies[1] of axisymmetric disturbances have revealed especially simple properties connected with conical flows. These properties tend to obviate the lengthy reduction necessary to obtain a density field from measured fringe shifts. The improved linearized theory for slender supersonic projectiles given by Whitham[2] offers the possibility of a similar simplification in the distant N-wave region between the front and rear shocks. Neglecting terms of second order in the perturbation velocities, an approximate expression for the density variation, just $1/\gamma$ times Whitham's equation for pressure, is used to evaluate the fringe shift integral in the N-wave far from the body. The resulting function exhibits projective properties similar to conicity along curves which are obtained from the front shock by a simple magnification of the radial coordinate. Measured and theoretical fringe shifts are compared for a number of cases. The possibility is discussed of deducing the $F(y)$-function of Whitham's theory from interferometric measurements along traces parallel to the axis of symmetry.

[1] Giese, Bennett, and Bergdolt, J. Appl. Phys. **21**, 1226 (1950).
[2] G. B. Whitham, Comm. Pure Appl. Math. **5**, 301 (1952).

X4. Visible Radiation from Helium in a Strong Shock Wave.* G. E. SEAY AND L. B. SEELY, JR., *Los Alamos Scientific Laboratory.*—Temperatures near 20 000°K with ion densities near 10^{18} cm^{-3} have been produced in helium by means of shocks. Helium was used because of its simplicity, but this choice eliminated usual shock methods because of the high sound speed and high ionization potential. Shock waves having sufficient strength and planarity were obtained by reflection against a glass plate of initially strong shocks produced by high explosives. Equilibrium calculations based on smear camera velocities of accurately plane shocks are believed to be pertinent if extremely low densities are avoided and if the measurements are not affected by radiative cooling. The light emitted consists of a continuum on which are superimposed some shifted and broadened lines of the normal helium spectrum. Impurity lines have been reduced to the α, β, and γ lines of hydrogen and two doublets of calcium. Measurements of helium line shift and width have been compared with theoretical values and are too large to be explained

by the Holtzmark ion theory, thus implying the necessity for consideration of electron effects.[1]

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Bennett Kivel, Phys. Rev. **98**, 1055 (1955).

X5. Transition Processes in Shock Wave Interactions.* ROBERT G. JAHN, *Lehigh University.*—Recent experiments in shock wave refraction have clarified a special type of shock outflow process which appears to have relevance to other shock interactions—notably shock reflection from an oblique wall. For certain incident shock strengths and angles of incidence (α) the air/methane refraction problem simulates closely the situation in the troublesome region of the reflection problem between the termination of the theoretical solutions (α_s) and the onset of Mach reflection (α_0) where the flow deflections cannot be reconciled with theoretically permissible reflected shock strengths. In the analogous refraction cases, the reflected shock is observed to increase in strength along its length to a maximum value at the intersection point, and to be followed by a subsonic rarefaction zone which also increases in severity near the intersection. In fact, this zone appears to coalesce into a subsonic discontinuity, just at the intersection point,—a feature which would contradict one of the basic assumptions of the regular reflection and refraction theories. Other refraction experiments suggest similar interpretation of the failure of three-shock theory in weak shock Mach configurations.

* Supported in part by the Office of Naval Research.

X6. Radio Studies of Atmospheric Turbulence.* J. W. HERBSTREIT, K. A. NORTON, PHILIP L. RICE, R. B. MUCHMORE,† M. C. THOMPSON, AND ROGER GALLET, *National Bureau of Standards.*—A summary is presented in this paper of progress made recently at the National Bureau of Standards, Boulder Laboratories, in understanding the nature of atmospheric turbulence in the troposphere. These studies were motivated by attempts to solve two important engineering problems: (1) the design of radio relay circuits depending upon the forward scatter of radio waves to points far beyond the radio horizon, and (2) the determination of the limiting accuracy of a microwave radio direction finding system. Physical reasons are given for preferring a particular mathematical form: $\rho K_1(\rho)$[1] for the correlation function describing the atmospheric turbulence, and experimental radio data are given for propagation paths both well beyond and well within the radio horizon which establish the correctness of the physical reasoning. A third independent source of evidence substantiating the theory is the direct measurement of the fluctuations of the refractive index of the atmosphere by means of a Birnbaum refractometer.

* This work was supported in part by the Air Force Cambridge Research Center, Air Research and Development Command.
† Ramo-Wooldridge Corporation, Los Angeles 45, California.
[1] $K_1(\rho)$ is the modified Bessel function of the second kind.

X7. Backscattering of Electromagnetic Waves from Ionospheric Turbulence. ALBERT D. WHEELON, *Ramo-Wooldridge Corporation.*—A theory of the propagation and back scattering of electromagnetic waves in an ionospheric layer containing homogenous turbulence is given. The ratio of received-to-transmitted power is calculated as a function of sweep frequency in the range 1 to 25 mc, corresponding to standard ionospheric pulse sounders. A single transmitting and receiving aerial is assumed, and the variations of radiation pattern with changing frequency are included. Near the E-layer's critical frequency ($\sim$3 Mc) refractive effects profoundly influence the scattering. At about 12 Mo, the viscosity cutoff to the turbulence decay spectrum converts the frequency dependence of power from a f^{-4} law to f^{-11}; thereby reducing scatter echos significantly above this frequency. The time correlation of back-scattered power is computed as a function of transmitter frequency, and the fading rate of the fluctuating signal shown to be a good indication of turbulent conditions in the E-region.

X8. Short Wavelength Scattering from a Dielectric Sphere.* S. I. RUBINOW, *Harvard University.*—The scattering of a plane wave by a dielectric sphere (or square well) is considered in the limit of ka very large. Debye's original asymptotic expansion of the scattering amplitude,[1] which essentially treats rays separately according to the multiplicity of the internal reflections, may be effectively summed. The transmitted ray yields the van de Hulst[2] (or Glauber) result when $ka(N-1)$ (N is the index of refraction) is small and may also be evaluated for $ka(N-1)$ large. The (once) reflected ray not only produces most of the scattering at large angles, but yields, at grazing incidence, the contribution to the total cross section due to diffractive scattering. The first correction term of the latter, of order $(ka)^{-\frac{1}{3}}$, is independent of N and is the same as it would be for a perfectly conducting (impenetrable) sphere. Generally, the diffractive effects are equally as important as the transmitted ray for forward scattering. Numerical comparison with exact computations for water drops and for square wells will be presented.

* This work supported by the U. S. Air Force.
[1] P. Debye, Ann. Physik **30**, 57 (1909).
[2] H. C. van de Hulst, Recherches astronom. obser. Utrecht **11** (1946).

X9. Excitation of Nitrogen by 2.4 kev Protons.* N. P. CARLETON, *Harvard University.*—Fast protons entering the upper atmosphere are apparently the primary source of the excitation of the aurora. Laboratory investigations of excitation by proton impact are therefore of aid in inferring from auroral spectra the fundamental processes occurring in the upper atmosphere. When 2.4 kev protons shoot into low-pressure nitrogen, they excite light, the principal features being the first negative system and Meinel's new system of N_2^+, the first positive system of N_2, and the Balmer lines. The N_2^+ systems are the most prominent. Observation of the dependence of the intensity of the various emissions upon the proton beam current and the nitrogen pressure gives evidence as to the exciting mechanisms. The conclusions are that the intense N_2^+ emissions are excited by a charge exchange which leaves the resulting N_2^+ ion in an excited state. The first positive bands of N_2 are excited not by proton impact, but by the impact of fast atoms, formed through charge exchange in earlier collisions. The Balmer series is produced primarily as a result of charge capture directly into an excited state. Vibration in the excited molecules is noticeably enhanced, and rotation is somewhat less enhanced, as compared with excitation by electron impact.

* This work was partially supported by the Air Force Cambridge Research Center.

SATURDAY AFTERNOON AT 2:00

NBS, East Building

(K. R. ATKINS presiding)

Invited Papers in Cryogenics

XA1. Some Paradoxes of Superconductivity. F. G. BRICKWEDDE, *National Bureau of Standards and University of Maryland.* (30 min.)

XA2. Spectra of Atoms Condensed at 4.2°K. C. M. HERZFELD, *National Bureau of Standards.* (30 min.)

SATURDAY AFTERNOON AT 1:30

Shoreham, West Ballroom

(E. O. SALANT presiding)

Cosmic Rays

Y1. Trapped Orbits in the Earth's Dipole Field.* S. F. SINGER, *University of Maryland.*—Charged particles of low rigidity can be trapped in allowed Störmer Q-regions with impact parameter $\gamma \leq -1$. These regions are normally blocked from infinity by forbidden Q-regions of varying extent. The block is removed and the inner region is filled when solar corpuscular streams perturb the dipole field strongly at large distances from the earth. Particles of moderate energy disappear rapidly by entering the atmosphere in the auroral zone through Q-region "horns." Very low rigidity particles remain within magnetic force tubes. Perturbation methods show that particles with pitch angle $\alpha_0 < 2\frac{1}{2}°$ (in the equatorial plane) enter the atmosphere and are absorbed. Particles with $\alpha_0 < 2\frac{1}{2}°$ are reflected back and forth and stored until they are scattered out or absorbed. In the meantime they drift and produce a "ring current." Scattering may also put particles into the empty region $\alpha_0 < 2\frac{1}{2}°$; these particles then enter the atmosphere. Applications to magnetic storms, aurorae, auroral ionosphere and airglow are discussed. We also discuss the contribution of atmospheric cosmic ray albedo to the particles in the Q-regions.

* Assisted by the Office of Scientific Research, U. S. Air Force.

Y2. Cosmic-Ray Latitude Effect at High Latitudes.* JOHN R. WINCKLER AND KINSEY A. ANDERSON, *University of Minnesota.*—The verticle flux of particles has been determined at depths in the atmosphere of 10 g/cm² and greater over a range of geomagnetic latitudes from 51°N to 64.2°N. Measurements were made with Geiger telescopes having stopping power of 0.17 g/cm² and 3.6 g/cm² at intervals of approximately 2° of latitude. The cosmic-ray intensity at 10 g/cm² increases with increasing latitude to at least 63°N. Within present knowledge of geomagnetic coordinates, this is equivalent to the energy of protons having a range of 10 g/cm², i.e., the atmosphere above the equipment. The integral spectrum does not obey a power law with constant exponent at energies below one Bev. In some cases simultaneous flights were made at 55° and at high latitudes. Fluctuations were observed at high latitudes, however, which could not be normalized away by this procedure. During one flight an excessively high counting rate was observed at 64.2°N at a depth of 7 g/cm² which was a function of atmospheric depth. These high altitude results are not inconsistent with measurements made by Neher[1] and Van Allen.[2]

* This work was supported in part by the U. S. Atomic Energy Commission and the Office of Naval Research.

[1] H. V. Neher and E. A. Stern, Phys. Rev. **98**, 845 (1955).

[2] Meredith, Van Allen, and Gottlieb, Phys. Rev. **99**, 198 (1955).

Y3. Abundance of Lithium, Beryllium, and Boron Nuclei at the Top of the Atmosphere. HERMAN YAGODA, *National Institutes of Health.*—A 73-cc block of G5 emulsion was flown horizontally in the tip of Viking Rocket No. 10 to a peak altitude of 218 km from White Sands, New Mexico ($\lambda = 41°$N) on May 7, 1954. Study of the six component pellicles (1500 microns thick) revealed the presence of 48 relativistic tracks of M-nuclei, 24 H-nuclei, and 5 tracks attributable to lithium and boron. After application of corrections for scanning efficiency and production of secondary L-nuclei in the rocket skin and while traversing the atmosphere the number of Li–Be and B-nuclei entering the detector is estimated to be 15 ± 9. The ratio of light to medium nuclei entering the atmosphere is 0.3 ± 0.2. While this estimate is of small statistical significance, it is largely free from uncertainties in the magnitude of the fragmentation probabilities of heavy nuclei traversing air, a factor which complicates the interpretation of measurements at balloon elevations. With a flight time of 411 sec above 30 km the flux of $M^\circ + H^\circ$ nuclei is 6.59 ± 0.8 (m²/sec sterad)$^{-1}$, in fair agreement with an estimate of 7.62 ± 1.4 secured on the flight of Viking Rocket No. 9. The M°/H° ratio corrected for fragmentation in condensed matter above the emulsions (2 g/cm^{-2}) is 1.96 ± 0.5.

Y4. Further Data on the Time Variation of Cosmic-Ray Heavy Nuclei.* M. KOSHIBA AND MARCEL SCHEIN, *University of Chicago.*—Approximately 1000 additional heavy nuclei of $Z \geqq 10$ were analyzed by using the method of a moving plate mechanism. The new results obtained confirm those reported previously. They yield a time variation of heavy nuclei, $Z \geqq 10$, having its maximum between 9:00 and 11:00 A.M. with an amplitude of about 30%. Three barometers were used in order to measure accurately the altitude variation during the Skyhook balloon flight, June 24, 1955. The pressure altitude measured with all barometers was the same within 5%. This excellent agreement excludes the possibility of an apparent time variation due to the failure of the barometer. In the final analysis a total of 1796 tracks of heavy nuclei

with $Z \geq 10$ were used. The position of the intensity maximum is close to the one expected for charged particles entering from the direction of the sun. To show that the effect is probably not due to an unusually large disturbance on the sun, the results were compared with Simpson's neutron data at Climax, Colorado, which showed no appreciable fluctuations at the time of our balloon flight. There seems to exist some indication of a correlation between the shape of the time variation curve of the heavy nuclei and that of the neutron component.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

Y5. Further Rocket Observations on Soft Radiation at Northern Latitudes.* F. B. McDonald, G. H. Ludwig, and J. A. Van Allen, *State University of Iowa.*—Eight successful flights of balloon-launched rockets were made in September, and October, 1955 at northern latitudes for further study of the soft radiation discovered[1] at high altitudes in 1953 and confirmed in 1954. The instrumentation consisted of (a) a pair of identical, independent Geiger tubes, one unshielded and the other shielded with 150 mg/cm² of lead and (b) a NaI(Tl) crystal scintillation counter placed under a thin titanium foil at the forward tip of the rocket nose. Five flights showed high counting rates such as previously reported. Counting rates as great as 75 times the cosmic-ray rate were observed. Detailed data from the eight flights will be presented.

* Assisted by the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Meredith, Gottlieb, and Van Allen, Phys. Rev. **97**, 201 (1955).

Y6. Nature of the High-Altitude Soft Radiation.* J. A. Van Allen and J. E. Kasper, *State University of Iowa.*—The latitude distribution of the incidence of the soft radiation[1] has been measured by 22 flights of essentially identical equipment at geomagnetic latitudes ranging from 54° to 89°N. The distribution bears a striking resemblance to the latitude distribution of visually observed aurorae. All observed data of the 1953, 1954, and 1955 series can be simulated by exposing the flight apparatus to laboratory beams of x-rays. It appears that the soft radiation as actually detected consists of x-rays of energy 10 to 100 kev and of intensity of order 10^5 photons/cm² sec. It is presumed that this radiation is bremsstrahlung from auroral electrons.

* Assisted by the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] See abstract Y5, this issue.

Y7. Differential Energy Spectrum of Alpha Particles.* P. S. Freier, J. E. Naugle, and E. P. Ney, *University of Minnesota.*—Preliminary measurements[1] have shown that the differential energy spectrum of alphas has a maximum at about 0.25 Bev/nucleon. Further scanning has been done to increase the statistical weight of the data. Final flux values will be presented and the significance of the results with respect to the origin of cosmic rays will be discussed.

* This work was supported in part by the U. S. Atomic Energy Commission and the Office of Naval Research.
[1] E. P. Ney, Proc., Guanajuata Conference on Cosmic Rays.

Y8. Criteria for the Consistent Counting of Delta Rays on Heavy Nuclear Tracks in Emulsion Plates.* Otis B. Young and William C. Ballowe, *Southern Illinois University.*—This paper is an attempt to improve greatly the consistency of delta-ray counting along tracks of heavy nuclei in emulsions. The problem is complicated and, unless satisfactory criteria are properly followed, variable results may be expected both from a given scanner and from different scanners. A set of criteria are given. Considerable information regarding their use is included. This work is adapted to nuclei with Z's of ten or greater.

* This research is performed cooperatively with the University of Chicago and is financially supported by the Research Corporation and by the Office of Ordnance Research, U. S. Army.

Y9. Methods for the Determination of Gap Length Distribution of Nuclear Emulsion Tracks.* J. Klarmann and R. A. Bryan, *University of Rochester.*—Two different methods, using a multiple-channel analyzer,[1] have been employed to measure the gap length distribution for tracks of low Z-components of the primary cosmic radiation. In previous methods the observer measured and recorded the length of each gap individually; in our methods the recording is automatic. At the end of a measurement the number of gaps longer than s microns for 8 adjustable values of s can be read off directly from the channel analyzer. In the first method the stage is driven at uniform speed along the track while in the second the observer moves at hairline along the track. In both methods the observer does not have to remove his eyes from the microscope for the duration of the measurement. Thus these methods seem to be more expedient than others previously described. Data indicating the sensitivity and range of application of both methods will be presented.

* This research supported in part by the Office of Scientific Research, Air Research and Development Command, U. S. Air Force.
[1] Kurt Enslein, "Time scaler for nuclear track gap counting," Rev. Sci. Instr. (to be published).

Y10. An Investigation of Large Cosmic-Ray Showers.* J. Linsley, W. L. Kraushaar, G. W. Clark, B. Rossi, J. Earl, and F. Scherb, *MIT.*—Some preliminary results have been obtained in an investigation of extensive air showers consisting of 10^6 to 10^8 particles at sea level. Eleven liquid scintillation counters, each of area 1 m², are distributed within a circle 1500 feet in diameter. In coincidence the counters detect large showers which strike that region. They sample the particle density and signal the instant of arrival at their various locations. Together these data fix, for each shower, the size, the direction, and the point of impact of the shower core. Individually the density samples trace out the lateral distribution. The primary subjects of the investigation are the directions of arrival and the energy distributions of the high-energy primary particles responsible for the shower. However, the preliminary results pertain mostly to direct measurements of the density of shower particles as a function of the distance from the core in the range from 1 to 1000 particles/m².

* This work was supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

Y11. Arrival Directions of Air Showers.* George W. Clark, *MIT.*—The celestial arrival directions of over 1000 showers generated by primaries with energies greater than 10^{15} ev have been determined by the method of timing. Preliminary results will be presented.

* This work is supported in part by the joint program of Office of Naval Research and the U. S. Atomic Energy Commission.

Y12. An Electron Shower Associsted with a Very Energetic He Nucleus. N. Seeman and R. G. Glasser, *Naval Research Laboratory.*—An unusual event has been observed in an emulsion stack exposed in a balloon flight near the geomagnetic equator. An extremely energetic particle whose ionization and delta-ray density imply a charge of two enters the stack at a zenith angle of 56°. After 62 mm, an electron pair, whose origin cannot be spatially resolved from the parent track, appears with an opening angle of approximately 0.001 radian attributable mainly to multiple scattering. The energy of the pair, from relative multiple scattering measurements, is 20 ± 4 Bev. The pair subsequently produces an electron shower. The geometry and the energy measurements both are consistent with the conclusion that the electron shower was initiated by the first pair. There is no evidence for any further electromagnetic processes related to the primary track. 13.7 cm after entering the stack the He nucleus collides forming a $6+43\alpha$ star containing a highly collimated "jet." The energy

of the primary particle, estimated from the angular distribution of the jet, is 1.7×10^{14} ev. No explanation giving this event a reasonable probability has been found. Bremsstrahlung of an α particle would have a probability of 10^{-5}, higher than any other hypothesis invoked.

Y13. Cosmic-Ray Production of Helium-3 and Tritium in Meteorites.* M. GALLI AND S. F. SINGER, *University of Maryland.*—The production of He^3 and H^3 in meteorites by cosmic-ray bombardment has important consequences for the origin of meteorites, as well as for the origin of cosmic rays. We have extended our earlier calculation[1] to include the depth dependence of He^3. We take account of various cosmic-ray data as well as the recent accelerator measurements of Fireman, and of Libby's group. The results are applied to the problem of mass loss of meteorites in space and in the atmosphere. The "formation age," "solidification age," and "breakup (or cosmic-ray) age" of meteorites are clearly distinguished. Conclusions are drawn about the prehistoric cosmic-ray intensity by viewing the meteorite as an integrating cosmic-ray meter.

* Assisted by Office of Scientific Research, U. S. Air Force.
[1] S. F. Singer, Nature **170**, 728 (1952).

SUPPLEMENTARY PROGRAMME

SP1. Inelastic Scattering of 14.8 and 19.0-Mev Protons by Li^6.*† R. SHERR, W. F. HORNYAK, AND H. YOSHIKI, *Princeton University.*—The angular distribution of protons scattered by Li^6 has been investigated at 14.8 and 19.0 Mev. Only protons from the ground state and the first excited state (2.2 Mev, 3+) appear as clearly resolved groups in the scintillation spectrum. The protons from the second excited state (3.6 Mev, 0+) appear weakly on the high-energy side of a broad group from a level at 4.5 Mev (~1.8-Mev wide at half-maximum). There are no clear indications of other identifiable (narrow) peaks in the remaining continuum of the spectrum. The "2.2-Mev" group was measured from 8° to 165° at 14.8 and 19.0 Mev. The inelastic group has a broad maximum at about 40° at both energies, and there is only a small difference in the cross sections at the two energies. The peak cross sections are 12 and 11 mb/sterad, respectively. The peak corresponds in angle to that expected if the distribution were $j_2(Qr)$ with $r=5\times10^{-13}$ cm. However, the peak is too broad to be fitted so simply. Theoretical discussion of the data will be given by Levinson *et al.*[1]

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
† To be called for at the end of Session M.
[1] Banerjee *et al.* and Levinson *et al.*, abstracts in this Bulletin.

Author Index to Papers Presented at the 1956 Washington Meeting

Allcock, G. R.—RA5
Almqvist, E., D. A. Bromley, H. E. Gove, A. E. Litherland, and E. B. Paul—N1
Amster, H. J., L. M. Culpepper, and W. E. Emmerich—MA7
Ascoli, G. and U. Haber-Schaim—EA1
Baker, James A. and Warren Fenton Stubbins—G8
Ball, William P., Rex Booth, and Malcolm H. MacGregor—J5
Ballam, J., G. K. Lindeberg, and C. G. McGrew—JA6
Banerjee, M. K., C. A. Levinson, C. H. Albright, and W. Tobocman—MA5
Baranger, Michel—RA10
Barkas, W. H.—QA5
Barkas, Walter H., Harry H. Heckman, and Frances M. Smith—JA2
Barnes, S. W., B. Rose, G. Giacomelli, and L. Velinsky—EA13
Barringer, R. L., L. S. Osborne, and R. Meunier—EA7
Bashkin, S., R. R. Carlson, and J. A. Jacobs—SA9
Beard, David B.—J13
Bedo, D. E. and D. H. Tomboulian—WA3
Bell, R. E. and H. M. Skarsgard—W8
Bendel, W. L., John McElhinney, and R. A. Tobin—M7
Benveniste, Jack, Calvin C. Gardner, M. Paul Nakada, and Calvin Wong—F4
Bergmann, Peter G.—RA3
Berko, S.—D7
Berkowitz, J., M. G. Inghram, and W. Chupka—PA3
Bernstein, Jeremy—DA10
Bersohn, R.—TA3
Bevington, P. R. and E. M. Bernstein—NA7
Beyster, J. R. and M. Walt—F9
Birkhoff, R. D., J. S. Cheka, H. H. Hubbell, R. M. Johnson, and R. H. Ritchie—J12
Blevins, M. E., M. M. Block, and E. M. Harth—EA12
Bloom, S. D. and C. M. Turner—G2
Blosser, H. G., T. H. Handley, and C. D. Goodman—W6
Blum, Jacques M.—UA2
Bockelman, C. K.—W3
Boehm, F., E. N. Hatch, P. Marmier, and J. W. M. Dumond—E2
Bollinger, L. M., R. E. Coté, P. Hubert, J. M. LeBlanc, and G. E. Thomas—C5
Bonner, T. W. and J. H. Slattery—F7
Bostick, Winston H. and David Finkelstein—CA6
Brabant, John M., Bruce Cork, Nahmin Horwitz, Burton J. Moyer, Joseph J. Murray, Roger Wallace, and William A. Wenzel—JA11
Brandt, Werner—UA6
Bratenahl, Alexander, H. Paul Hernandez, Jack M. Peterson, B. Smith, Ralph H. Stahl, and Charles J. Taylor—G10
Breit, Gregory—A3
Brickwedde, F. G.—XA1
Brockhouse, B. N.—K9
Bromley, D. A., H. E. Gove, A. E. Litherland, E. B. Paul, and E. Almqvist—N2
Brown, H. A.—KA2
Brown, R. J. S.—TA10
Browne, Cornelius P.—SA13
Broyles, A. A.—CA7
Brueckner, K. A.—HA11
Brugger, R. M., J. E. Evans, E. G. Joki, and R. S. Shankland—F11
Butler, J. P., T. A. Eastwood, T. L. Collins, M. E. Jones, F. M. Rourke, and R. P. Schuman—K4
Butler, J. W., C. R. Gossett, and H. D. Holmgren—B8
Cameron, A. G. W.—M1
Campbell, E. C. and P. H. Stelson—J9
Carleton, N. P.—X9
Carlson, R. R. and S. Bashkin—SA7
Carter, R. S., D. J. Hughes, and H. Palevsky—Q1
Casabella, P. A. and P. J. Bray—TA5
Chew, G. F. and U. Haber-Schaim—DA3
Childress, James D.—KA1
Chretien, M., J. Leitner, N. Samios, M. Schwartz, and J. Steinberger—JA7
Chupka, W., J. Berkowitz, and M. G. Inghram—PA4
Church, E. L.—HA6
Clark, George W.—Y11
Clifton, Donald F. and Lee Gildart—WA9
Coester, F.—MA3
Cohn, H. O. and J. L. Fowler—F6
Cole, F. T., L. J. Laslett, and J. N. Snyder—G5
Collins, R. L.—TA8
Cool, R. L. and O. Piccioni—EA10
Corben, H. C.—HA8
Corliss, L. M., J. M. Hastings, and N. Elliott—KA7
Coté, R. E., L. M. Bollinger, J. M. LeBlanc, and G. E. Thomas—K5
Cox, S. A. and R. M. Williamson—N4
Crosbie, E. A. and M. Hamermesh—RA12
Crouch, M. F., V. E. Krohn, and G. R. Ringo—F12
Cumming, J. B., C. A. Swartz, and G. Friedlander—W11
Dabbs, J. W. T., L. D. Roberts, and G. W. Parker—R9
Das, T. P.—TA2
Davis, Raymond, Jr.—UA5
Davisson, J. W.—FA4
Dillon, J. F., Jr.—KA4
Donahue, T. M., W. H. Kasner, and C. B. Leffert—PA7
Donnellan, J. E., F. Hutchinson, and R. Braams—P10
Drachman, Richard J. and Gerald Feinberg—DA8
Drell, S. D., M. H. Friedman, and F. Zachariasen—DA2
Dubey, V. S., C. E. Mandeville, and M. A. Rothman—B12
Dudley, John M., Fred W. Inman, and Robert W. Kenney—J3
DuPouy, Gaston—L1
Ecker, G.—CA4
Efremov, N.—PA12
Einbinder, Harvey—PA9
Eisen, F. H. and C. E. Birchenall—WA11
Eisner, E.—VA11
Elliott, N., L. M. Corliss, and J. M. Hastings—KA6
Elton, L. R. B.—DA11
Emmerich, W. S. and R. M. Sinclair—MA9
Endt, P. M., C. H. Paris, A. Sperduto, and W. W. Buechner—W1
Enge, H. A., W. W. Buechner, A. Sperduto, and M. Mazari—SA12
Enoch, J. and R. G. Sachs—DA1
Fagg, L. W., E. H. Geer, and E. A. Wolicki—C4
Fairbank, W. M., M. E. Blevins, M. M. Block, M. J. Buckingham, E. M. Harth, and G. G. Slaughter—U11
Fano, U.—L4
Fawcett, E.—U5
Feingold, Arnold M.—HA9
Ferguson, A. J. and H. E. Gove—HA4
Ferrell, Richard A.—U2, V4
Fink, R. W., G. W. Warren, B. L. Robinson, and R. R. Edwards—E5
Finkelstein, David—RA4
Ford, G. and R. R. Lewis—MA12
Fowler, W. A., C. W. Cook, C. C. Lauritsen, T. Lauritsen, and F. Mozer—M2
Franklin, Jerrold—DA4
Freeman, A. J.—NA5
Freier, P. S., J. E. Naugle, and E. P. Ney—V7
Friedlander, M. W.—QA3
Fritts, R. W. and S. Karrer—WA8
Frye, Glenn M., Jr., and Juanita H. Gammel—N7
Fukuda, N.—HA10
Furth, H. P. and R. W. Waniek—WA5
Gabor, Dennis—L2
Galli, M. and S. F. Singer—V13
Geer, E. H., H. D. Holmgren, R. L. Johnston, and E. A. Wolicki—SA4
Geltman, Sydney—VA12
Gerhart, J. B. and R. Sherr—MA11
Gerstein, G., J. Niederer, and K. Strauch—M9
Ghosh, S. N. and W. F. Sheridan—PA5
Gilbert, Francis C., Charles E. Violet, and R. Stephen White—JA3
Gilbert, T. L.—KA3
Glashow, S. and W. Selove—HA1
Glassgold, A. E. and A. Galonsky—HA3
Goland, A. N. and A. W. Ewald—WA7
Gold, L.—T9
Goldberg, Irwin, Allen Janis, Ezra Newman, and Peter G. Bergmann—RA2
Goldberg, N.—R7
Goldhaber, G., R. W. Birge, W. W. Chupp, G. Ekspong, S. Goldhaber, J. E. Lannutti, D. H. Perkinn, D. H. Stark, and L. Van Rossun—JA13
Goldstine, H. H.—S4
Good, M. L., Hugh Bradner, F. S. Crawford, and M. L. Stevenson—EA11
Gordy, Walter and Howard Shields—P1
Gossett, C. R., J. W. Butler, and H. D. Holmgren—W5
Gottfried, K.—MA4
Gove, H. E., A. E. Litherland, E. Almqvist, and D. A. Bromley—N3
Green, Milton—WA12

Grimm, G., J. S. Desjardins, J. Rosen, J. Rainwater, and W. W. Havens, Jr.—F14
Grodzins, L.—B10
Gross, E. P., E. A. Jackson, and S. Ziering—X1
Gupta, Ishwar C., Allen L. Snyder, and W. Y. Chang—JA10
Halbert, M. L., T. H. Handley, and A. Zucker—M11
Hamermesh, B.—V2
Hanson, H. P.—NA11
Harth, E. M., M. E. Blevins, M. M. Block, M. J. Buckingham, W. M. Fairbank, and G. G. Slaughter—G1
Hatch, E. N., P. Marmier, F. Boehm, and J. W. M. Dumond—E1
Haugsnes, Jack—K2
Havens, W. W., Jr., G. Grimm, J. S. Desjardins, J. Rosen, and J. Rainwater—F15
Hawgood, John—VA14
Heckman, Harry H., Frances M. Smith, and Walter H. Barkas—JA12
Heer, C. V. and R. A. Erickson—U3
Heikes, R. R. and W. D. Johnston—KA9
Hein, R. A. and M. C. Steele—U6
Heinberg, Milton and Lorne A. Page—D5
Henderson, J. W. and J. S. Koehler—Q4
Henry, Warren E.—U4
Herbstreit, J. W., K. A. Norton, Philip L. Rice, R. B. Muchmore, M. C. Thompson, and Roger Gallet—X6
Hersh, Herbert N.—T4
Herzfeld, C. M.—XA2
Heydenburg, N. P. and G. M. Temmer—C3
Hill, R. W.—F1
Hintz, N. M. and R. M. Eisberg—HA13
Holland, Dan H.—DA6
Holmgren, H. D., R. L. Johnston, E. A. Wolicki, and E. H. Geer—SA2
Hornig, James F. and Joseph O. Hirschfelder—PA10
Hornyak, W. F.—N10
Horwitz, N., J. J. Murray, and W. E. Crandall—W12
Householder, A. S.—S3
Huang, Kerson and C. N. Yang—VA9
Hudis, J. and A. A. Caretto—W10
Hughes, D. J.—QA2
—— and V. E. Pilcher—K12
Huizenga, J. R., D. W. Engelkemeir, M. S. Freedman, F. T. Porter, and J. E. Gindler—E7
Hwang, C. P., C. D. Fulton, and W. M. Fairbanks—U1
Imhof, W., E. Knapp, and V. Perez-Mendez—EA8
Inchauspé, Nicolas—Q12
Jacobs, J. A., S. Bashkin, and R. R. Carlson—SA8
Jahn, Robert G.—X5
Jastram, P. S., C. M. Schroeder, and R. C. Sapp—E10
Jenkins, T. L.—D1
Johnson, R. G., O. E. Johnson, and L. M. Langer—B1
Johnston, R. L., E. A. Wolicki, E. H. Geer, and H. D. Holmgren—N12
Jung, R. G. and M. L. Pool—E11
Juveland, A. C. and W. Jentschke—M10
Kaiser, H. F.—G12
Kane, J. V. and S. Frankel—E9
Kendall, H. and L. Grodzins—B11
Kerner, Edward H.—PA8
Kilb, Ralph W. and Chun Chia Lin—NA3
Kilkson, Rein and F. Hutchinson—P7
King, D. T.—EA4
King, Jean I. F.—VA10
Klarmann, J. and R. A. Bryan—V9
Koch, H. W., J. E. Leiss, and J. S. Pruitt—NA9
Koehler, W. C. and E. O. Wollan—KA10
Korringa, J.—TA11
Koshiba, M. and Marcel Schein—V4
Koski, W. S. and R. P. Hamlen—TA4
Kraus, O., R. E. Michel, and W. H. Tanttila—TA6
Kriessman, C. J. and S. E. Harrison—KA5
Krone, R. W. and W. G. Read—SA11
Kruse, P. W.—Q11
Kurath, D.—HA5
Kurbatov, J. D., H. J. Sathoff, Jr., K. Hisatake, and M. Sakai—B5
Kusch, P.—H2
Lamb, W. E.—H1
Landauer, J. K.—Q8
Landauer, R., D. R. Young, and M. E. Drougard—KA12
Lane, R. O. and J. E. Monahan—K1
Langsdorf, Alexander, Jr.—V1
LaRocque, Armand P.—CA11
Larsson, K. E., R. L. Zimmerman, and H. Palevsky—J4
Laufer, John and Robert McClellan—X2
Lazar, N. H. and G. D. O'Kelley—B9
Lebowitz, Joel L. and Peter G. Bergmann—VA4
Leder, Lewis B.—CA8
Leiss, J. E. and J. M. Wyckoff—N9
Leitner, J., M. Chretien, N. Samios, M. Schwartz, and J. Steinberger—JA8
Leonard, Stanley L.—D3
Levin, Jules S. and Lawrence Cranberg—F8
Levine, M. A., H. Furth, and R. Waniek—KA13
Levinson, C. A., M. K. Banerjee, C. H. Albright, and W. Tobocman—MA6
Lewis, H. W., J. W. Olness, and W. Haeberli—SA15
Lide, D. R., Jr., D. E. Mann, and R. M. Fristrom—NA6
Lidofsky, L., K. Jones, R. Bent, J. Weil, T. Kruse, M. Bardon, and W. W. Havens, Jr.—SA10
Lin, Lan-Ying and M. E. Caspari—T3
Linden, Bernard R.—NA12
Linsley, J., W. L. Kraushaar, G. W. Clark, B. Rossi, J. Earl, and F. Scherb—V10
Lipps, F. W.—CA10
Long, T. R. and Charles S. Smith—Q7
Luckey, D. and R. R. Wilson—EA3
Maczuk, J., R. M. Showers, and B. P. Fabricand—WA2
Magnusson, L. B. and D. W. Engelkemeir—E8
Malenka, B. J. and E. Feenberg—RA6
Marion, Jerry B. and Gustav Weber—SA1
Markley, F. W. and T. R. Palfrey, Jr.—M4
Markowitz, Samuel S., F. S. Rowland, and G. Friedlander—W9
Marton, L.—L3
Mast, C. B. and C. J. Mullin—HA2
Mateosian, E. der and M. Goldhaber—R6
Mather, R. L.—J8
McCormick, Gene and Walter Gordy—P2
McDonald, F. B., G. H. Ludwig, and J. A. Van Allen—Y5
McGowan, F. K., P. H. Stelson, and M. M. Bretscher—C1
McGuire, T. R.—FA1
McKelvey, J. P.—WA1
McLean, E. A., V. E. Scherrer, and C. E. Faneuff—PA1
McVoy, Kirk W. and Eugene Guth—J11
Mebane, Banks H.—RA8
Merat, Parviz—RA1
Merzbacher, E. and J. R. Herring—VA13
Metropolis, Nicholas—S2
Meunier, R., L. S. Osborne, and R. L. Barringer—EA6
Miller, R. C. and C. S. Robinson—D2
Miller, W. F.—PA6
Mitchell, D. and H. Levinstein—WA10
Mize, J. P. and J. W. Starner—E6
Moak, C. D. and A. Galonsky—N8
Mobley, R. C.—G14
Moore, M. N.—VA3
Morinaga, H., E. L. Robinson, and E. Bleuler—B3
Morowitz, Harold J.—P8
Need, John L. and Charles D. Goodman—M12
Nelkin, M. S. and D. B. MacMillan—K8
Nelson, C. M. and J. H. Crawford, Jr.—T6
Newkirk, Lester L., Henry C. Catron, Malcolm H. MacGregor and Charles J. Taylor—K10
Ney, E. P., John Naugle, and P. S. Freier—UA3
Niemann, F. L., J. K. Bowker, W. M. Preston, and J. C. Street—EA2
Nozières, Philippe and David Pines—CA1
Occhialini, G.—QA4
Oldenberg, Otto—PA2
Olness, J. W., W. Haeberli, and H. W. Lewis—SA14
Ore, Aadne and Ernest C. Pollard—P6
Osher, John E., Burton J. Moyer, and Sherwood I. Parker—JA4
Overhauser, A. W. and R. L. Gorman—Q5
Patten, C. G., D. B. Beard, J. A. Jungerman, and P. G. Lichtenstein—J14
Paul, William and D. M. Warschauer—WA6
Peaslee, D. C.—RA7
Penner, S. and C. S. Robinson—EA5
Penning, J. R., H. R. Maltrud, J. C. Hopkins, and F. H. Schmidt—B2
Percus, Jerome K. and George J. Yevick—VA6
Peterson, Vincent Z.—EA9
Petritz, R. L.—FA3
Pierce, Louis—NA2
Pilcher, V. E., D. J. Hughes, and J. A. Harvey—K6
Pines, David and Philippe Nozières—CA2
Plaskett, John—FA5
Pollard, Ernest and Jane Setlow—P11
Porter, C. E. and H. Feshbach—MA10

Potnis, V. R.—E3
Pratt, G. W., Jr., and J. H. Wood—VA8
Prosser, F. W., Jr., M. S. Moore, and J. P. Schiffer—B7
Pruitt, J. S. and S. R. Domen—NA10
Quisenberry, Karl S., T. T. Scolman, and A. O. Nier—UA7
Rainwater, J., G. Grimm, and W. W. Havens, Jr.—F13
Raka, E. C., R. R. Kassner, M. Plotkin, and J. Spiro—G3
Rasmussen, John O. and Donald Strominger—R4
Raz, B. J. and J. B. French—W2
Rexroad, Harvey N. and Walter Gordy—P4
Ritchie, R. H.—CA5
Roberts, L. D., J. W. T. Dabbs, G. W. Parker, and R. D. Ellison—R8
Roggen, Arend van, Lien van Roggen, and Walter Gordy—TA7
Rose, David and Bernard Hamermesh—K13
Rose, M. E., L. D. Roberts, and J. W. T. Dabbs—R10
Rosen, L. and A. H. Armstrong—W7
Rosenbaum, B. and K. R. Atkins—U8
Rosenthal, Jenny E.—Q9
Rossi, A., H. Frauenfelder, N. Levine, and Sidney Singer—B6
Rubin, Robert J.—VA2
Rubinow, S. I.—X8
Sagane, Ryokichi, Walter F. Dudziak, and James Vedder—EA14
Salmi, E. W., J. R. Beyster, and M. Walt—MA8
Salwen, H., W. Sadowski, and P. G. Bergmann—VA5
Schacklett, Robert L. and Jesse W. M. Du Mond—UA4
Schardt, A. W. and B. J. Dropesky—B4
Scharff-Goldhaber, G. M. McKeown, and J. W. Mihelich—R3
Schiffer, J. P., Alfred A. Kraus, Jr., and J. R. Risser—SA3
Schindler, A. I.—FA2
Schrack, R. A., R. C. Placious, and L. Marton—CA9
Schumann, R. W.—K11
Schwartz, R. B., V. E. Pilcher, and R. M. Schectman—K3
Seaborg, G. T.—A2
Sears, G. W. and R. V. Coleman—Q2
Sears, W. C. and W. W. Parkinson—PA14
Seay, G. E. and L. B. Seely, Jr.—X4
Seeman, N. and R. G. Glasser—V12
Seemann, Karl W.—NA8
Seki, H., K. R. Atkins, and E. U. Condon—U9
Sessler, A. M., J. N. Snyder, and K. R. Symon—G4
Setlow, Richard B.—P9
Shapiro, A. M., M. Widgoff, D. Fournet, A. Pevsner, D. Ritson, R. Schluter, V. Henri, and V. Fitch—JA5
Sharp, W. T.—RA13
Sherr, R. and W. F. Hornyak—N11
——, W. F. Hornyak, and H. Yoshiki—SP1
Shields, Howard, W. B. Ard, and Walter Gordy—P3
Shrader, R. E., S. Larach, and I. J. Hegyi—T1
Siegel, Armand—VA1
Silsbee, R. H.—T2
Silver, A. H. and P. J. Bray—TA12
Simms, P. C. and R. M. Steffen—R5
Singer, L. S. and W. J. Spry—TA1
Singer, S. F.—Y1
Sinnott, K. M.—NA4
Sirlin, A.—J2
Slaughter, G. G., M. M. Block, and E. M. Harth—JA9
Slepian, Joseph—J1
Slovacek, R. E.—K7
Smith, R. V.—F2
Snell, A. H.—V5
Sperduto, A. and W. W. Buechner—W4
Stahl, Ralph H., Alexander Bratenahl, James A. Galvin, Roy K. Mullins, Jack M. Peterson, and Charles J. Taylor—G11
Steele, M. C.—WA4
Steenberg, N. R.—MA1
Steininger, D. H. and F. D. Bennett—X3
Stelson, P. H. and F. K. McGowan—C2
Stephenson, John L.—PA13
Stern, Frank—T8
Sternheimer, R. M.—MA2
Stevenson, M. L. and A. H. Rosenfeld—RA9
Stewart, John W.—U7
Stewart, M. G., A. J. Bureau, and C. L. Hammer—R2
Stone, R. S. and R. E. Slovacek—J10
Sugarman, R. M.—J7
Swank, R. K. and W. L. Buck—J6
Swann, C. P. and F. R. Metzger—SA6
Symon, K. R. and A. M. Sessler—G6
Takahashi, Yasushi—DA5
Tatro, C. A., R. O. Haxby, T. R. Palfrey, Jr., and R. M. Whaley—M3
Taylor, Charles J., Alexander Bratenahl, H. Paul Hernandez, Jack M. Peterson, Bob H. Smith, and Ralph H. Stahl—G9
Telegdi, V. L.—D6
Teng, Lee C.—G7
Thomas, L. H.—S1
Thomson, J. O.—T5
Tolhoek, H. A.—QA1
Toms, M. Elaine and John McElhinney—M6
Torrey, H. C.—TA9
Treiman, S. B. and R. G. Sachs—DA7
Triebwasser, S.—KA11
Trigger, Kenneth R.—UA8
Überall, H.—RA11
Valk, H. S. and B. J. Malenka—DA9
Van Allen, J. A. and J. E. Kasper—V6
Van Ostenburg, D. O. and D. J. Montgomery—Q6
Vegors, Stanley H., Jr., and R. B. Duffield—R1
Wada, W. W. and K. A. Brueckner—HA12
Wadey, W. G. and L. Rosler—G13
Wall, N. S. and W. F. Waldorf—M8
Walt, M. and J. R. Beyster—F10
Walters, G. K. and William M. Fairbank—U10
Walton, R. B. and J. D. Clement—SA5
Waniek, R. W.—UA1
Warren, G. W. and R. W. Fink—E4
Wattenberg, A., A. Odian, P. C. Stein, and R. Weinstein—DA12
Watts, G. and R. Setlow—P5
Weber, Gustav and Jerry B. Marion—N6
Weinrich, M. and L. M. Lederman—EA15
Weir, C., S. Spinner, I. Malitson, and W. Rodney—T7
Weizel, W. and G. Ecker—CA3
Weneser, J. and E. L. Church—HA7
Whalen, J. A.—D4
Wheeler, Albert D.—X7
Whetstone, Albert L., Paul F. Yergin, and J. Halpern—M5
Whitehead, Marian, Donald H. Stork, Donald H. Perkins, James R. Peterson, and Robert W. Birge—JA1
Widom, B.—PA11
Wiegand, C. E.—C7
Wiegand, D. A.—Q10
Wilkinson, M. K. and J. W. Cable—KA8
Williams, J. H.—V3
Wills, James E., Jr.—F3
Wilson, E. Bright, Jr., Ralph W. Kilb, and C. C. Lin—NA1
Winckler, John R. and Kinsey A. Anderson—V2
Wolcott, N. M. and P. L. Smith—Q3
Wolicki, E. A., E. H. Geer, H. D. Holmgren, and R. L. Johnston—N5
Wolke, R. L.—C6
Wong, Calvin, Jack Benveniste, Calvin C. Gardner, and M. Paul Nakada—F5
Yagoda, Herman—Y3
Yevick, George J. and Jerome K. Percus—VA7
Young, Otis B. and William C. Ballowe—V8
Zahlan, A. and E. P. Gross—TA13
Zucker, Alexander—A1

Editor's Report on *The Physical Review*

Every year the Editor's report begins with the statement that *The Physical Review* is still growing. Our journal grows faster than the membership of our Society. The Editor's office receives frequent suggestions for the solution of its publication problems. So far, all of these proposals have been impractical or more expensive than the present procedure. A frequently proposed remedy is to furnish members with Abstracts only and to sell reprints of the complete Articles to those who request them. This was tried by The Physical Society of London but had to be abandoned because of the heavy financial burden.

Our problem might be alleviated by the appearance of new journals in competition with *The Physical Review*. The existing excellent journals in specialized fields of physics help insofar as their specialties overlap with the subject matter printed in *The Physical Review*, but for various reasons they do not siphon off a sufficiently large amount of material.

STRICT SELECTION OF SUBJECTS

From now on we must, to our regret, become much stricter about the subject matter of Articles submitted for inclusion in *The Physical Review*. To be acceptable, a paper must contain a clearly expressed new physical idea or new measurements of physical quantities. Technical details should be included only if they help the reader to judge the validity and accuracy of the reported observations; the detailed description of apparatus should be published elsewhere. Papers about a new instrument should explain the new physical ideas involved, and the new or improved measurements of physical quantities which are expected from it, but should omit construction details. Theoretical papers must clearly state their basic premises and conclusions but can leave much of the mathematical derivations to the reader. We wish to stress, however, that we do not want short and obscure papers, but rather, fewer and clearer papers.

It is not possible to give a sharp and useful definition of the subject matter which we consider belongs in *The Physical Review*. We can, however, give some examples of the kind of papers which we are reluctant to accept. We shall continue to reject papers whose content is primarily of value for technical applications or instrumentation. Letters and Articles intended as advertisements of more complete treatments published elsewhere will be rejected. Papers on applied mathematics, applied mechanics, and fluid dynamics will be accepted only if they have a very direct bearing on physics problems. Another class of articles that we shall discourage consists of papers on ostensibly "fundamental" theory which appear to be merely brilliant exercises in mathematics or are purely philosophical contemplations without any relation to physical data. They often cause the reader to ask, "So what?"

The hardest task of the editor is to recognize and to make decisions about borderline cases. For example, the gap between technical uses and basic knowledge is almost nonexistent in solid state physics. It would help if authors in this field would emphasize their contribution to the understanding of the structure of matter even though their research was performed in an environment stressing the applications.

AMERICAN DOCUMENTATION INSTITUTE

We would like to encourage more use of the American Documentation Institute auxiliary publications project for the recording of extensive tabular material, additional details of apparatus, technique, and calculation, and other supplementary material that is worth placing on permanent record for reference by a few specialists but is not essential to the understanding of the work by the larger group of interested readers. The American Documentation Institute accepts this supplementary material only from the Editor of the journal where the article appears, and keeps it on permanent file. An appropriate footnote is inserted in the article. [For the suggested forms, see J. C. Slater and G. F. Koster, Phys. Rev. **94**, 1511 (1954); K. Kambe and J. H. Van Vleck, Phys. Rev. **96**, 69 (1954); or W. E. Nervik and G. T. Seaborg, Phys. Rev. **97**, 1095 (1955).] Interested readers may then obtain photostats or microfilm at a nominal fee. (The document number and price are inserted in galley.)

The use of the American Documentation Institute, which is set up under the auspices of the Library of Congress photoduplication service, seems to us to provide a more permanently accessible and official repository for supplementary material than duplicate copies of internal laboratory reports which are obtained from the author as long as his supply lasts.

SPLITTING AND ALTERNATE ISSUES

The policy of splitting the subject matter into alternate issues was in general favorably received. It was intended as a preliminary to an actual split of *The Physical Review* into two journals. Since this drastic step is not yet being taken, we have now abandoned the alternate issue system. It may have been of minor advantage for the convenience of some readers, but it caused considerable delay in

the publication of papers. Only a true split into two sections, each of which appears twice a month, would bring *The Physical Review* back to a more manageable size.

Subscribers begin to complain about the excessive shelf space required for *The Physical Review*. We believe, however, that, with the rapid development of physics, the content of *The Physical Review* becomes obsolete in a few years. There is really little reason to keep more than about "six feet" of *The Physical Review* at home. It is so much better to fill the shelves with current books since these contain only those results published in *The Physical Review* and elsewhere that are worth perpetuating. A complete home file of *The Physical Review* may even lead authors to an inexcusable neglect in quoting important articles from other journals available in libraries. For home use, we recommend the thirty-year index of *The Physical Review* (1921–1950, Volumes 17–80) as a valuable aid in locating references.

SPEED OF PUBLICATION

The normal time for publishing an article is from four to four and one-half months after receipt. With prompt refereeing this can occasionally be shortened by a month. The large flow of incoming papers necessitates a strict routine in the editorial procedures. The unfortunate result is that even minor defects in a submitted paper, such as faulty figures, unacceptable notation, and other numerous author's oversights, cause delays of a month or more. We can assure speedy publication only if the manuscript closely follows the rules of the *Style Manual* (obtainable from the American Institute of Physics, 57 East 55th Street, New York 22, New York—$1.00 per copy) and the "Information for Contributors" (printed in the first issue of each volume of *The Physical Review*). This is often done most easily by following the notation, punctuation, reference, and footnote styles of a recent article on the same subject.

It is very important that manuscripts submitted as Letters to the Editor be in perfect form. The whole advantage of speedy publication and special editorial handling is lost if delays are caused by author's oversights. We check the Letters carefully and far too often find objectionable defects such as faulty units, unexplained abbreviations, or obvious mistakes which the author should have caught before submittal and which only he can correct. We have a special grudge against authors who first impress on us the importance of their work by submitting a Letter and then withdraw it after it is in page proof.

Our policy to restrict the Letter column only to more urgent contributions is bearing fruit; the number of Letters has decreased further and is now about 15 per issue. Articles, however, have become longer. From an average of 5.5 pages per article in 1954, they have grown to 6 pages per article in 1955. Let us hope that they have become more understandable.

THE BULLETIN

Begining with 1956, the *Bulletin of the American Physical Society* will no longer be reprinted in *The Physical Review*. Its status is raised to that of a separate journal with K. K. Darrow as Editor. Besides the usual abstracts, this new journal will contain notes on the council meetings and occasional other matters relating to our Society. It will continue to be sent free to members and for five dollars a year to nonmembers. There will be enough extra copies available at each meeting so that the copies received through the mails can be kept unblemished for future binding.

This will also have the advantage that the index of each volume of *The Physical Review* will be half as long as before and thus more manageable. The December 15 issue of *The Physical Review* will henceforth contain an author index covering the four volumes which appeared during the year.

ADVISORY COMMITTEE

The publication problems of the Society have become very complex. Many important decisions regarding our journals depend upon information which belongs in the domains of the Treasurer, the Secretary, and the American Institute of Physics. For this reason, an advisory committee on publication policy has been established with the Managing Editor as chairman and further consisting of the Society's Treasurer and Secretary and their deputies, and the Director and Executive Secretary of the American Institute of Physics. This committee combines the information needed to decide, for example, the size of journal issues and to keep track of costs, editorial staff size, and other current problems.

STATISTICS

Some statistical data are given in the appended table. The number of Articles increased by 30 and the number of pages by 680 compared to 1954. These numbers are, however, misleading. In order to speed up the publication of the December issues, about 35 longish Articles covering more than 250 pages were postponed to the January 1 issue. On the other hand, the year 1955 contained 100 more pages of meeting abstracts as a result of the new policy regarding the *Bulletin*. Thus, normally, the increase would have been 65 articles and 830 pages.

About 16% of the manuscripts received were rejected or withdrawn. The breakdown is as follows: 1% were crack-pot contributions; 4% were

recommended for publication in other journals; 3% were withdrawn by the authors; 8% were rejected for being below our standards or for duplicating, to a large extent, previously published material. (Many papers are returned with severe criticisms and are never resubmitted.)

The cost of printing and editing *The Physical Review* increased from $273 000 to $308 000. The income was approximately as follows: from nonmember subscriptions $83 000, from member subscriptions $31 000, from page charges $120 000, from back-number sales, $5000—a total of about $239 000. Thus, $69 000 has to be contributed from membership dues towards the support of *The Physical Review*. This amount was about $76 000 last year. The increase in cost was just about canceled by the necessary increase in page charge which went into effect July 1, 1955.

ACKNOWLEDGMENTS

The rapid growth of *The Physical Review* has added immeasurably to the publication problems of the American Institute of Physics and the printing load of the Lancaster Press. Both of these organizations deserve much credit for the efficient way in which they have surmounted these difficulties.

It is impossible to overestimate the thanks we owe to the many referees. Their untiring efforts are responsible for keeping the high standards of our journal. As Editor, I wish to express our appreciation for their help. I am sure that all will agree also that our Assistant Editor, Simon Pasternack, does an unusually excellent job as is evidenced by many letters we receive from grateful authors.

S. A. GOUDSMIT

STATISTICAL APPENDIX

American Physical Society Membership and Total Published Material

	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955
Members	5714	6711	7949	8888	9472	10 428	10 889	11 230	11 612	12 000
Pages	1734	2248	3446	3946	3920	4720	4829	5798	6880	7560
Articles	187	281	392	496	524	619	684	916	1105	1135
Letters	207	344	473	657	816	883	653	538	516	347

The American Physical Society

OFFICERS OF THE SOCIETY FOR 1956

President	E. P. WIGNER	Princeton University
Vice-President	H. D. SMYTH	Princeton University
Secretary	K. K. DARROW	Bell Telephone Laboratories (Office at Columbia University)
Treasurer	G. B. PEGRAM	Columbia University
Managing Editor	S. A. GOUDSMIT	Brookhaven National Laboratory
Local Secretary for the Pacific Coast	W. A. NIERENBERG	University of California, Berkeley

Past Presidents now on Council: W. F. G. Swann, H. A. Bethe, and R. T. Birge.

Elected Members of the Council: L. I. Schiff, W. Shockley, John Bardeen, A. O. Nier, F. Seitz, A. M. Weinberg, S. K. Allison, and N. F. Ramsey.

Please cut along this line

(To be sent to Dr. R. D. Huntoon, National Bureau of Standards, Washington 25, D. C.)

I EXPECT to attend the dinner of the American Physical Society at seven o'clock on Friday evening, April 27. My party will comprise ..... persons.

(*Name*).....

(*Address*).....

(If you want your tickets held to the time of the banquet itself, send a check, made out to American Physical Society, for $4.00 per plate.)